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Wind energy rejection in China: Current status, reasons and perspectives

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ABSTRACT

Currently, parts of the potential energy generated by the wind turbines could not be transmitted to the electric power grid in China, leading to a serious wind energy rejection problem. In some local areas (e.g. Gansu province), the wind energy rejection rate reaches 47% in the first half year of 2016. Wind energy rejection problem is currently the biggest barrier for the further development of the wind energy in China. In this review, the current status of the wind energy rejection (between 2010 and 2016) are reviewed with a detailed analysis of the reasons based on the statistical data released by the authorities. Two cases studies (Inner Mongolia Autonomous Region and Gansu province respectively) are also performed to specify the reasons for the rejection and provide an in-depth discussion on the influences of related policies. Based on the recent trends and policies, several solutions and perspectives are also given together with some specific suggestions for the policy makers. Furthermore, in this review, a brief description of China's electric system is also given for the convenience of the readers. This review is not only informative for solving the wind energy rejection problem in China but also helps the policy makers in other developing countries for building the roadmaps of the renewable energies.

Contents

Abbreviations: AC, Alternating Current; CCG, Central China Grid Company Limited; CEC, China Electricity Council; CMA, China Meteorological Administration; CNREC, China National Renewable Energy Center; CSPG, China Southern Power Grid Company Limited; CREIA, Chinese Renewable Energy Industries Association; CWEA, Chinese Wind Energy Association; CWERA, Wind and Solar Energy Resource Center, China Meteorological Administration; DC, Direct Current; ECG, East China Grid Corporation; EPDI, Electric Power Dispatching Institution; GDP, Gross Domestic Product; IMP, Inner Mongolia Power (Group) Co., LTD; IEC, International Electrotechnical Commission; LVRT, Low Voltage Ride Through; NDRC, National Development and Reform Commission; NREL, National Renewable Energy Laboratory; NCGC, North China Grid Company Limited; NEG, Northeast China Grid Company; NCG, Northwest China Grid Company Limited; PHESPP, Pumped Hydro Energy Storage Power Plant; STM, Sample Turbine Method; SWPG, Southwest Power Grid; SERC, State Electricity Regulatory Commission; SGCC, State Grid Corporation of China; TEPC, Tibet Electric Power Company; UHV, Ultra-high Voltage; WPD, Wind Power Density; WTG, Wind Turbine Generator; WWEA, World Wind Energy Association.

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1. Introduction

Wind energy is one of the important renewable energies, currently being developed worldwide. In the recent five years, the total installed capacity of wind energy in China increases rapidly, serving as the leading country and occupying 34.03% of the total installed capacity of the world [1, p.7]. Meanwhile, a large amount of wind energy can not be connected with the power grid of China, leading to serious wind energy rejection. Here, rejection means that the electricity dropped by the wind farms due to some undesirable situations (e.g. grid safety and no available transmission lines). For details of the definition of the rejection and related China's national standard, readers are referred to Section 4.

Between 2010 and 2016, the overall wind energy rejection rate in China is above 10% [2,3]. In the first half year of 2016, the wind energy rejection problem becomes more serious. Based on the statistical data released by the National Energy Administration (China) on July 27th 2016 (http://www.nea.gov.cn/2016-07/27/c_135544545.htm), the overall wind energy rejection rate in China is 21%, which is 6% more than the rate of the year of 2015. Specifically, ten provinces out of thirty two provinces (or equivalent cities) in total have wind energy rejection problem and the rejection rate of nine of them is above 10%. Astonishingly, the wind energy rejection rate in the Gansu province and Xinjiang Autonomous Region is 47% and 45% respectively. Hence, a detailed analysis of the reasons for the above phenomenon is of great importance for the wind energy development in China and worldwide.

In this review, current status, reasons and solutions (with perspectives) of wind energy rejection problem are reviewed in great details based on the analysis of a large amount of reliable data and related policies. Many illustrating examples are given for the reader' s convenience with many typical figures and informative tables. The following sessions of this review are arranged as follows. In Section

Nomenclature

Roman/Greek letters

E_{rej}	total wind energy rejection
E_{mn}	actual wind energy generation of a selected sample turbine
$\tilde{E}_{mn}$	actual wind energy generation of a specific wind turbine
M	number of wind farms
N	number of the periods or different types of turbines
$P_{\max}$	maximum power output by the wind turbine within certain duration
$P_{\min}$	minimum power output by the wind turbine within certain duration
P_{rated}	rated power of the wind turbines
ΔP	fluctuation of the active power
$\Delta\bar{P}$	non-dimensional fluctuation of the active power using rated power
$\Delta\tilde{P}$	overall averaged power fluctuation
ΔP_i	fluctuation of the active power fluctuation within a given time period
σ	standard deviation of the fluctuation of active power outputted by a single wind turbine
$\bar{\sigma}$	non-dimensional standard deviation of the fluctuation of active power

2, the wind energy resource and its development in China will be briefly introduced. In Section 3, the characteristics of the wind energy is shown. In Section 4, an overview of the current status of the wind energy rejection in China will be introduced together with the statistics of several selected provinces. In Section 5, the reasons for wind energy rejection in China are proposed with the examples and discussions of the situations in several selected provinces. In Section 6, the solutions and perspectives of the wind energy rejection in China are suggested and discussed based on recent policies and trends. In Section 7, the concluding remarks of this review are given with an emphasis on the suggestions to the policy makers in the developing countries.

For the convenience of the readers, plenty of appendixes are given at the end of the present paper, providing detailed information and some background introduction of China's wind energy system. For readers who are not familiar with the electric system of China, please refer to Appendix A for a brief introduction. In the Appendix B, the possible routes for the connections of the wind energy to the grid are given and discussed in the view of policy. In the Appendixes C and D, detailed information on the heat supplying and hydrogen generation projects using wind energy are given together with a complete list of related projects. In the Appendix E, a case study of Inner Mongolia Autonomous Region (serving as the largest wind energy base in China) is performed to specifically discuss reasons for local energy rejection. In the Appendix F, another case study of Gansu province is given in order to shed light on the influences of policy on the wind energy rejection.

2. The resources and development of wind energy in China

2.1. An overview of wind energy resources

The wind energy resources can be quantitatively measured by the wind power density (WPD), which is defined as the mean annual power available per square meter of the swept area of a wind turbine in different heights above the ground. WPD is calculated based on the wind velocity and the air density. According to an index proposed by the National Renewable Energy Laboratory (NREL), the wind energy resources can be classified into seven classes based on the values of the WPD and the wind speed (as shown in Table 1). High class corresponds to high intensity of WPD and fast wind speed. The parameters for the above classification also depend on the heights above the ground. Table 2 shows the classification of wind energy resources using wind power density defined by China national standard GB/T 18,710–2002 [5, p.5, table 4] released in 2002.

The wind turbines are classified based on the annual averaged wind speed and turbulence. Table 3 shows the International Electrotechnical Commission (IEC) standard 61400-1 for the classification of the wind turbine generator (WTG). Classes I to IV refer to the difference in the annual averaged speed at hub height and A or B refers to the different turbulence level.

Table 4 shows the summary of the estimated wind energy in the mainland of China released by different institutes [3, p.35, table 3–1; p.38, table 3–2]. According to Table 4, the total amount of the wind energy resources in China is very rich and is of the

Table 1
Classes of wind power at the heights 10 m and 50 m according to the wind power density and the wind speed. The table was collected from the National Renewable Energy Laboratory (NREL, USA) [4, Table 1–1].

Wind power class*	10 m[a] (33 ft)		50 m[a] (164 ft)	
	Wind power density (W/m^2)	Speed[b] m/s (mph)	Wind power density (W/m^2)	Speed[b] m/s (mph)
1	0	0	0	0
2	100	4.4 (9.8)	200	5.6 (12.5)
3	150	5.1 (11.5)	300	6.4 (14.3)
4	200	5.6 (12.5)	400	7.0 (15.7)
5	250	6.0 (13.4)	500	7.5 (16.8)
6	300	6.4 (14.3)	600	8.0 (17.9)
7	400	7.0 (15.7)	800	8.8 (19.7)
	1000	9.4 (21.1)	2000	11.9 (26.6)

The following notes were directly adapted from the website of the National Renewable Energy Laboratory [4]:
"*NOTE*: Each wind power class should span two power densities. For example, Wind Power Class = 3 represents the Wind Power Density range between 150 W/m^{2}and 200 W/m^2."

[a] Vertical extrapolation of wind speed is based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

Table 2
The national standard of the classification of the wind power in China. The table was collected from the national standard of China "Methodology of wind energy resource assessment for wind farm (GB/T)18710-2002) [5, p.5, Table 4]. For detailed information about the calculation of wind speed, readers are referred to Ref. [5].

Wind power class	10 m		30 m		50 m	
	Wind Power Density /(W/m^2)	Speed /(m/s)	Wind Power Density /(W/m^2)	Speed/(m/s)	Wind Power Density /(W/m^2)	Speed/(m/s)
1	< 100	4.4	< 160	5.1	< 200	5.6
2	100–150	5.1	160–240	5.9	200–300	6.4
3	150–200	5.6	240–320	6.5	300–400	7.0
4	200–250	6.0	320–400	7.0	400–500	7.5
5	250–300	6.4	400–480	7.4	500–600	8.0
6	300–400	7.0	480–640	8.2	600–800	8.8
7	400–1000	9.4	640–1600	11.0	800–2000	11.9

Table 3
Classification of the wind turbine generator. The table was collected from IEC Standard 61400-1 [6].

Wind turbine class	Annual-average wind speed at hub-height (m/s)	Extreme 50-year gust in meters/second (miles/hour)	Turbulence
Ia High wind	10.0	70.0 (156)	18%
Ib High wind	10.0	70.0 (156)	16%
IIa Medium wind	8.5	59.5 (133)	18%
IIb Medium wind	8.5	59.5 (133)	16%
IIIa Low wind	7.5	52.5 (117)	18%
IIIb Low wind	7.5	52.5 (117)	16%
IV	6.0	42.0 (94)	N/A

same level with the United States of America. For example, at the height of 80 m above the ground, the technical available wind energy resource (with wind speed reaching 6.5 m/s) is 9,100 GW, comparing with 10,500 GW in USA. According to the international standard, the technical available wind energy resources in China at the height of 50 m, 70 m and 100 m (with the averaged wind power density above or equaling 300 W/m^2) are 2,000 GW, 2,600 GW and 3,400 GW [7, p.28].

Table 5 shows the distribution of the wind energy resource over China in terms of provinces at the height of 70 m above the ground [2, p.93, table 3–6]. Based on the Table 5, one can find that the distribution of the wind energy resource of China mainly covers several provinces in the northwest of China (Xinjiang Autonomous Region and Gansu province), the northeast of China (Heilongjiang, Jilin, Liaoning provinces) and the north China (Hebei province, Inner Mongolia Autonomous Region). Those provinces occupy above 90% of the total wind energy resource of China. In terms of the wind energy resource at the height of 70 m above the ground, Inner Mongolia province is of the largest amount of the wind energy.

Table 5
The potential technical available capacity of wind energy at the height of 70 m above the ground over China in terms of provinces or autonomous regions. The table was collected from "Renewable energy data manual 2015" released by China National Renewable Energy Center [2, p.93, table 3–6].

Province	Potential technical available (GW)	Technical available (GW)	Available area (km^2)
Inner Mongolia	1631.26	1459.67	394,919
Xinjiang	475.43	435.55	111,775
Gansu	264.46	236.34	61,342
Heilongjiang	134.15	96.51	29,580
Jilin	79.85	62.84	22,675
Liaoning	78.24	59.81	20,409
Hebei	86.51	41.88	11,870
Shandong	40.28	30.18	8472
Ningxia	17.77	15.55	4417
Jiangsu	3.73	3.70	926

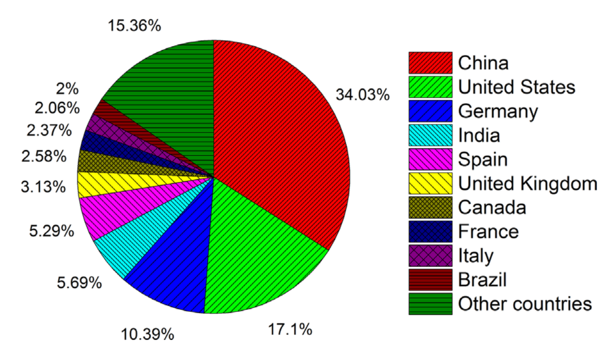

Fig. 1. Top ten countries of the wind energy development among the world in terms of the ratio of the installed capacity of wind turbines. The data were collected from World Wind Energy Assocaition (WWEA) up to the end of 2015 [1, p.7].

2.2. Wind energy development in China

In the recent five years, wind energy shows rapid development

Table 4
The summary of the estimated wind energy in the mainland of China released by different institutes. The data were collected from "The renewable energy industry development report 2015" [3, p.35, table 3–1; p.38, table 3–2].

Institutes	Year	Available area (km^2)	Height (m)	Wind Power Density (W/m^2)	Technical available (GW)
The second national survey	1990s	–	10	–	253
The third national survey	2007	200,000	10	≥ 150	297
China meteorological administration	2007	540,000	50	≥ 400	2680
United Nation Environment Program	2004	284,000	50	≥ 400	1420
Energy Research Institute	2007	200,000	–	–	600–1000
China meteorological administration	2009	–	50	≥ 300	2380
China meteorological administration	2014	–	70	> 150	7200
		–	70	> 200	5000
		–	80	> 150	10,200
		–	80	> 200	7500

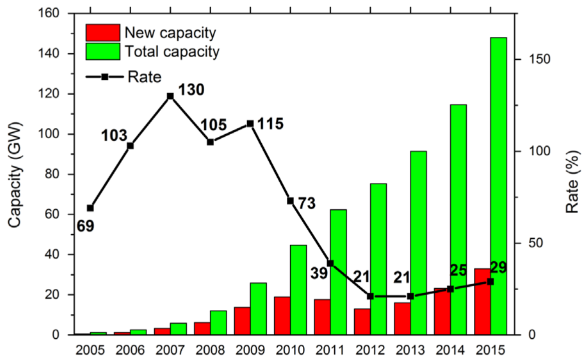

Fig. 2. The statistical data of the variations of the new installed capacity and total installed capacity of the wind energy in China versus the year. The data between 2005 and 2014 were collected from the Chinese Wind Energy Association (CWEA) [8, p.39, figure 2]. The data of 2015 were collected from [1, p.7].

in China. Fig. 1 shows the installed capacity of the wind energy in the top ten countries up to the end of 2015. According to the data from World Wind Energy Association (WWEA) [1, p.7], the total installed capacities of the wind energy in the world and China are 434.856 GW and 148 GW respectively. Hence, China occupies 34.03% of the total amount of the world, being the leading country. In 2015, the total installed capacity of the wind energy increases 32.97 GW. According to the data released by the National Energy Administration (in the file "Development of the Wind Power Industry in 2015"), the total installed capacity of the wind energy in China is 8.6% of the total installed capacity of all types of energies.

Fig. 2 shows the statistical data of the variations of the new installed capacity and total installed capacity of the wind energy between 2005 and 2015. The increasing rate of each year is also shown in the figure. One can find that the wind energy in China shows a rather rapid increase especially in the past five years. According to the China's national plan of the wind energy development up to the year 2050 [9], the wind energy will generate up to 17% of the total electricity in the general case, playing an important role on the power system [9, p. 6]. In 2050, the installed capacity of the wind energy will occupy 25–30% of the total capacity [9, p. 58]. The estimated installed capacities of the wind energy in 2020, 2030, and 2050 are 200 GW, 400 GW and 1000 GW [9, p. 6].

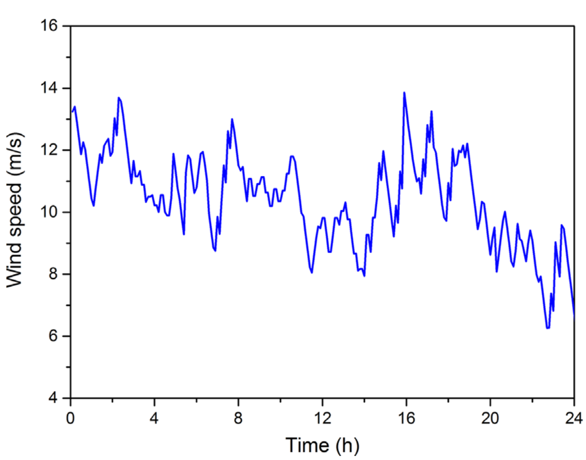

Fig. 3. A demonstration example of the fluctuation characteristics of the wind speed. The data were continuously collected for 24 h from a wind farm in China with 600 sampling points. The figure was plotted based on the data adapted from Ref. [10, p. 61, figure 1].

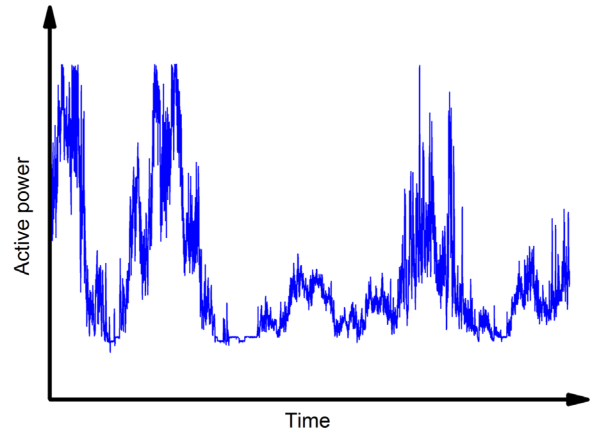

Fig. 4. A demonstration example of the fluctuation characteristics of the output power of a single wind turbine. The data were continuously collected for 12 h from a wind farm in the Inner Mongolia Autonomous Region of China on February 4, 2013. The sampling interval was 5 s.

3. The characteristics of the wind energy

3.1. Randomness

Wind energy shows strong randomness. In the natural world, the directions and speeds of the wind change rapidly depending on the seasons, locations, time periods and atmospheric motion. This is a quite complex phenomenon, leading to the difficulties in the long-term predictions of the wind power. Fig. 3 shows an example of the fluctuation of the wind speed within 24 hours measured in a wind farm. One can find great randomness of the wind speed in the above figure, leading to strong fluctuation of the output power of the local wind turbines (as shown in Fig. 4).

The above feature of wind energy is quite different with the traditional power plant, which can generate the predefined power according to the order of the administration authorities. Hence, great challenges are raised by the large-scale wind energy on the whole electric power system, including dispatching, transmission and connection to the power grid.

3.2. Fluctuations

The fluctuations of the energy output of wind farms can be represented by the two parameters (the variation and the standard

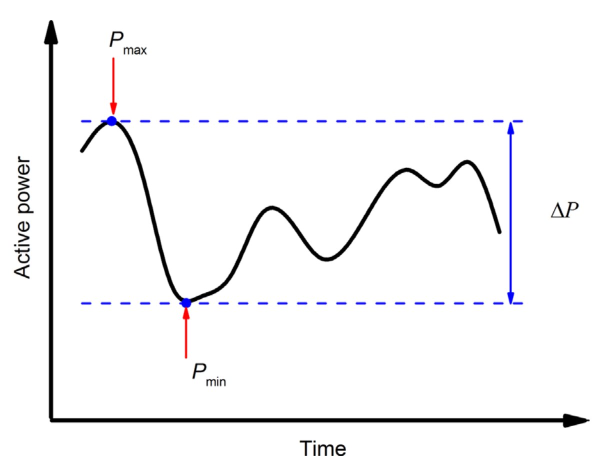

Fig. 5. Definition of the fluctuation of the active power of a wind turbine. The data of the wind power were collected from a wind farm in the Inner Mongolia Autonomous Region of China. For the definitions of the symbols, readers are referred to the Eq. (1).

deviation of the active power respectively). The variation of the active power outputted by a single wind turbine within a given period is defined as

$$\Delta P = P_{\max} - P_{\min}. \tag{1}$$

Here, ΔP is the fluctuation of the active power within the aforementioned time period; $P_{\max}$ is the maximum power outputted by the wind turbine; $P_{\min}$ is the minimum power outputted by the wind turbine. For the definitions of the above parameters, readers are referred to Fig. 5.

Now, influences of the probability of the events on the calculation of ΔP are discussed. In the dataset of active power, some signals with very high (or low) instantaneous power (but with very low probabilities) usually exist in the data. According to Eq. (1), those events significantly affect the calculated value of ΔP in the certain period hence the connection of the wind farms to the grid (referring to Section 4.2). However, due to the limited probability, the negative effects of those events on the safety of the system can be ignored in most cases.

In order to avoid the events with small probabilities, the $P_{\max}$ and $P_{\min}$ employed in Eq. (1) could be calculated within the 97% probability. To do this, the following procedure is suggested by us. Firstly, the data of the active power is re-arranged according to their possibilities. Then, all the events with low probabilities (within 1.5% in the high power and lowest power sides respectively) are dropped. The remaining data are then employed for the calculation of fluctuation of the active power using Eq. (1). This method is commonly employed during the analysis of pressure fluctuations in the hydro turbines according to International Electrotechnical Commission (IEC) standard. However, in the China's national standard (referring to Section 4.2), the influences of the event probability have not been considered yet.

The standard deviation of the fluctuation of the active power outputted by a single wind turbine (represented by σ) is [11]

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\Delta P_i - \Delta\tilde{P}\right)^2}. \tag{2}$$

Here, N is the number of the time periods involved in the calculations; ΔP_i is the fluctuation of the active power fluctuation within a given time period indexed by i; $\Delta\tilde{P}$ is the overall averaged power fluctuation.

Eqs. (1) and (2) could be also non-dimensionalized using the rated power of the wind turbines (P_{rated}) as follows [11]:

$$\Delta\bar{P} = \bar{P}_{\max} - \bar{P}_{\min}, \tag{3}$$

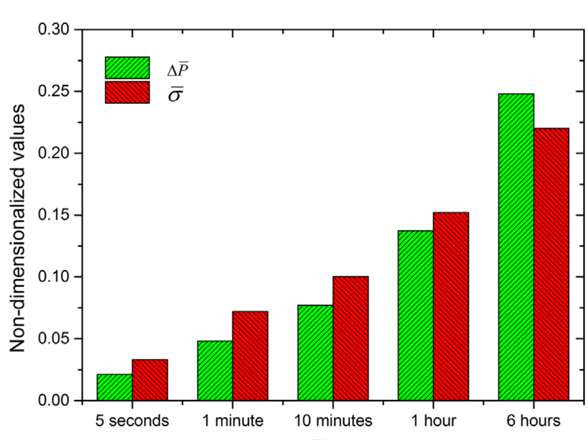

Fig. 6. The statistical data of the fluctuation characteristic of a single wind turbine in different time scales. The data were plotted based on table 5–2 of [11, p. 228]. For the definitions of the symbols, readers are referred to the Eqs. (3) and (4).

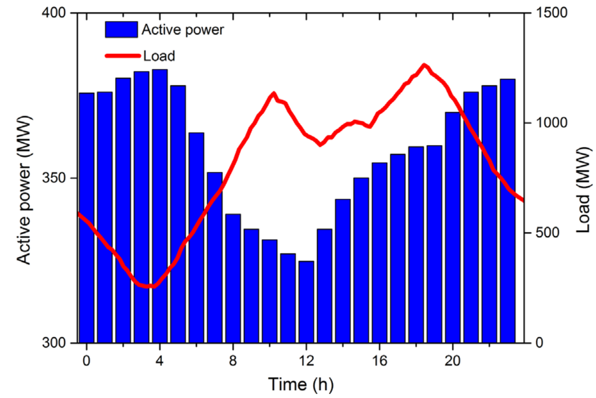

Fig. 7. Comparisons between the variations of the active power of the wind energy and the load of the electrical demand within a day. The data of the demand load were collected from [12, p.14, figure 2–3] and the data of wind energy generation were collected from [13, p. 16, figure 2–1].

$$\bar{\sigma} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\Delta\bar{P}_i - \Delta\bar{\tilde{P}}\right)^2}. \tag{4}$$

The over bar denotes the non-dimensionalized values using P_{rated}. For the wind farms or the group of wind farms, Eqs. (1)–(4) are also valid with the related parameters replaced using the corresponding values. Fig. 6 shows the values of the non-dimensional fluctuation of the active power ($\Delta\bar{P}$) and related non-dimensional standard deviation ($\bar{\sigma}$) in different time scales (5 seconds, 1 minute, 10 minutes, 1 hour and 6 hours respectively). Basically, the non-dimensionalized fluctuation of the active power and the standard deviation increase with the increase of the time scale.

3.3. Mismatch with the demand curve

Generally, the generation of the wind energy does not match well with the demand curve. Fig. 7 shows a schematic view of the wind energy generation and the demand curve. During the daytime, there are two peaks in the demand load with one during 9 o′ clock-12 o′clock and another one during 18 o′clock-20 o′clock [12, p.14, figure 2–3]. Basically, during the daytime, the electricity demand is high while the generation of wind energy is quite low due to the limited speed of the wind. However, during the late night, the situation is reverse, i.e. high wind energy generation with low electricity demand.

3.4. Impacts of wind energy on the electrical grid

The aforementioned characteristics of the wind energy generation could pose serious problems on the current electric grid. In the existing grid, the system was designed basically based on the traditional power plant (e.g. thermal or hydro power plants). For those traditional types of energy generation units, the power generation is fixed and totally controllable. Hence, there are no randomness and fluctuation on the active power as the case of wind energy. Moreover, the wind turbine could also absorb reactive power from the grid. Therefore, the connection of the wind energy to the grid poses great challenges on the traditional systems, leading to further modification of the system and built of more matched units (e.g. energy storage power plant). The impacts of the wind energy on the electric grid can be categorized into four groups [14, Chap.11.3] based on the affected parameters of grid (including reactive voltage, quality, stability and peak adjustment).

Firstly, wind energy could affect the reactive voltage. The power absorbed by the devices from the grid can be divided into the active power and the reactive power. The device could transform the active power into other kinds of energy (e.g. mechanical or thermal energies). For example, a pump could use the active power from the grid to levitate the water from the low levels to the high levels. The reactive power is the power used by the device for the creation or maintenance of the magnetic field. Different with the active power, which outputs energy to others, the reactive power is employed mainly for rotating the rotors in the generator in order to accomplish the movement of the mechanical parts. The wind turbines could absorb a large amount of the reactive power if the number of the installed turbines are significant. When there are not enough reactive power compensation devices (e.g. compensating capacitors), the voltage of the grid will be influenced. For a detailed example of the aforementioned influences, readers are referred to p.340 of Yang [14].

Secondly, wind energy could lead to frequent oscillations of the grid voltage and the generation of high-order harmonics.

Thirdly, in the current status, the giant wind farms could seriously affect the operational stability of the electric grid. For a small amount of wind turbines, when the grid fault happens, those turbines could protect themselves simply through the isolation from the grid. However, with the rapid increase of the size and the capacity of the wind turbines, the old fashioned method could lead to very serious problems on the grid stability. The current standard requires the wind turbines should have the ability of low voltage ride through (LVRT), which means that the wind turbines should connect to the grid during the fault (e.g. an event with a low voltage) in order to help the grid recover from those faults.

Fourthly, the randomness of the nature of the wind energy requires the increase of the peak adjustment units in the grid (e.g. energy storage units). With the development of the techniques, the traditional thermal power plant are also more and more involved into the peak adjustment due to the increase of the penetration levels of the wind energy.

4. Wind energy rejection in China

4.1. Calculation of wind energy rejection

4.1.1. Definition of wind energy rejection

In 2013, State Electricity Regulatory Commission (SERC) of China (currently being a division of the National Energy Administration of China) defines the wind energy rejection and related calculation method in the file "Calculation method of wind energy rejection (a tentative version)" [15]. In the SERC file [15], the wind energy rejection is defined as the total amount of the electrical energy, which could be generated by the wind turbines according to the wind resources, but is dropped by the wind farms due to the limits of the electrical transmission lines or the potential safety problems in the electric power grid. In the above definition, the energy losses due to the various kinds of faults in the wind turbines are excluded. Table 6 shows the typical faults in the wind turbines, leading to the energy loss. In Table 6, the faults are categorized into three groups with specific descriptions of each type.

Table 6
Types of energy loss due to the faults of the wind turbines. The table was created based on Ref. [14, p.292].

Types of faults	Descriptions of the position of faults
Control system	Sensor; relay; feedback loop; input/output interface module; controller module; program
Electric system	Circuit device; switch; bus; motor; transformer; power transformer; capacitor
Mechanical system	Blade; hub; main shaft; gear box; yaw; pitch control; braking system

4.1.2. SERC recommended methods

In the file "Calculation method of wind energy rejection (a tentative version)" [15], SERC recommended the "sample turbine method" (STM) to the operators of wind farms and electric power dispatching institution (EPDI). When the EPDI gave the orders to the wind farms to put a limit to the wind energy generation, the sample turbines in the wind farms will not be affected by the limit in general cases. Hence, the sample turbines could still generate the wind energy as much as they can. Then the total wind energy rejection can be calculated by the following formula

$$E_{rej} = \sum_{m=1}^{M} \sum_{n=1}^{N} (E_{mn} - \tilde{E}_{mn}), \tag{5}$$

where E_{rej} is the total wind energy rejection in the wind farm; E_{mn} is the actual wind energy generation of a selected sample turbine; $\tilde{E}_{mn}$ is the actual wind energy generation of a specific wind turbine when the EPDI put a limit to the wind energy generation of the wind farm; N and M refer to the different types of turbines and the number of wind farms.

The selection of the sample turbines should follow the following rules as required by EPDI [15]:

1. The total amount of the sample turbines should not exceed the 10% of the wind farms.
2. The sample turbines should be representative, e.g. different locations, series, and capacities.
3. If the selected sample turbines are out of operations, the other turbine adjacent to those turbines can replace them and a report about the above changes should be sent to EPDI.
4. The time period of the wind energy rejection should be calculated based on the order of EDPI.
5. For some extreme cases, all the wind turbines (including the sample turbines) in the wind farms are shut down. Hence, the output power of the wind farms before the shutdown can be employed for the calculation of wind energy rejection.

The execution of the above rules in the wind farms is monitored by SERC, who releases the data of the wind energy rejection status regularly.

4.2. Standards for the transmission of wind energy to the electric grid

In order to maintain the grid stability, several standards have been setup for the transmission of wind energy to the electric power grid. In China, the first national standard was released in 2005 [16]. Later, in 2009, the State Grid Corporation of China released an updated version of the standard [17]. In 2011, the revised national standard was released [18]. In those standards, a detail requirement for the transmission of wind energy to the electric grid has been given including limits on many parameters of the

Table 7
The permitted variations of the active power of a wind turbine for the grid connection according to the China's standard [18, p.2, table 1]. This table was translated based on China's standard. The values shown in the table are the suggested ones by the standard to the related companies.

Capacity of wind turbine (MW)	Maximum variations within 10 min (MW)	Maximum variations within 1 min (MW)
< 30	10	3
30–150	Capacity/3	Capacity/10
> 150	50	15

Table 8
The required operation time of the wind turbines in the electric power system with frequency variations. This table was translated based on Ref. [18, p.5, table 3].

Frequency variations	Requirements for turbine operations
< 48 Hz	depending on the lowest working frequency
48–49.5 Hz	> 30 min
49.5–50.2 Hz	Continuous
> 50.2 Hz	> 2 min

wind turbines (e.g. frequency, active power, reactive power and voltage, LVRT ability).

Table 7 summarizes the (suggested) permitted variations of the active power of wind turbine for the connection to the electric grid according to the China's standard. The permitted variations of the active power depend mainly on the two parameters i.e. capacity of wind turbine and the duration of variations. Table 8 gives the required ability (in terms of times of operations) of the wind turbines operating under the electric power grid with frequency variations.

Table 9 shows a full list of the electric power grid companies in China (including their sub-companies if any) together with their operational zones. In total, there are only three electric power grid companies in China. Currently, the State Grid Corporation of China is the largest grid company in China, covering a vast majority of China. The China Southern Power Grid Company Limited is the second largest one, covering five provinces in the southern part of China. Both of the above two grid companies are governed by the central government. The Inner Mongolia Power (Group) Co., LTD covers eight cities of the western part of Inner Mongolia Autonomous Region. To be emphasized, Inner Mongolia Power (Group) Co., LTD is the only grid company which is governed by the local province-level government (e.g. Inner Mongolia government).

4.3. Current status of wind energy rejection in China

4.3.1. An overview

In this section, an overview of the wind energy rejection in China between 2010 and 2016 is given. Fig. 8 shows the statistics of the wind energy generation and rejection in China during 2010–2015. The quantity of the electricity generated by the wind turbines with connection to the grid is marked as red. The quantity of the electricity due to wind energy rejection is marked as green with the rejection rate given. In 2016, the wind energy rejection rate is 21%, reaching the highest level of the history.

Based on Fig. 8, one can find that the total quantity of the wind energy connecting to the grid are increasing rather rapidly from 49.4 TWh in 2010 to 186.3 TWh in 2015 (with the increment 277%). However, the total quantity of the wind energy rejection is also very significant. In the year of 2015, the rejected wind energy is 33.9 TWh. The averaged rejection rate over six years is above 10%. Those figures all reflect the seriousness of the wind energy rejection problem in China. Currently, the wind energy rejection is one of the most challenging barriers for the development of the renewable energies in China.

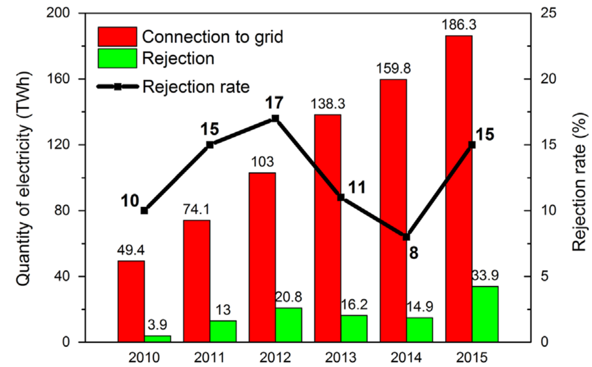

Fig. 8. The stastics of the wind energy generation and rejection in China during 2010–2015. The quantity of electricity generated by the wind turbines with connection to the grid is marked as red. The quantity of electricity due to wind energy rejection is marked as green with the rejection rate. For 2015, the data were collected from the website of National Energy Administration [19]. Parts of the data of the generation capacity and wind energy rejection between 2010 and 2014 were collected from the basic data of the electric power released by China Electricity Council. Parts of the data of the wind energy rejection and rejection rate between 2010 and 2012 were collected from p.44 of "Report on wind energy rejection in China" by Zhaobin Wang publlished on "Energy (in Chinese)" issue 7 of 2014, pages 42–48. Parts of the data of the wind energy rejection and rejection rate between 2013 and 2014 were collected from Ref. [2, p.141, table 4–28].

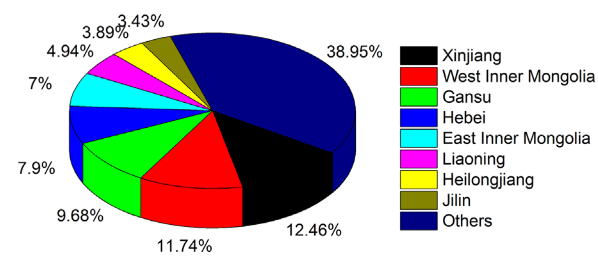

Fig. 9. The ratio of the grid-connection installed capacity of wind turbines in the selected provinces in China to the total installed capacity. The data were collected from National Energy Administration of China [19], The data of Inner Mongolia Autonomous Region were collected from the bulletin of wind power generation in 2015 by Inner Mongolia electric power association [Website:http://www.nmgzzqdlhyxh.com/hygl_84/Show_3147.html].

Table 9
A list of the companies in China relating with electric power grid together with their operational zones.

Name	Sub-companies	Operational zones
State Grid Corporation of China	Northeast China Grid Company	Heilongjiang; Jilin; Liaoning; East Inner Mongolia (Chifeng; Tongliao; Hulun Buir; Xinganmeng)
	Northwest China Grid Company Limited	Shaanxi; Gansu; Ningxia; Qinghai; Xinjiang
	North China Grid Company Limited	Beijing; Tianjin; Hebei; Shanxi; Shandong
	East China Grid Corporation	Shanghai; Jiangsu; Zhejiang; Anhui
	Central China Grid Company Limited	Hubei; Hunan; Jiangxi; Henan; Fujian
	Southwest division	Sichuan; Chongqing; Tibet
Inner Mongolia Power (Group) Co., LTD	–	West Inner Mongolia (Xilingol, Ulanqab, Hohhot, Baotou, Ordos, Wuhai, Bayan Nur, Alxa)
China Southern Power Grid Company Limited	Guangdong Grid Company	Guangdong
	Guangxi Grid Company	Guangxi
	Yunnan Grid Company	Yunnan
	Guizhou Grid Company	Guizhou
	Hainan Grid Company	Hainan

Table 10
The quantity of electricity and the rate of wind energy rejection of selected provinces or autonomous regions in China between 2010 and 2015.

Companies	Province	2011		2012		2013		2014		2015	
		Quantity (TWh)	Rate (%)	Quantity (TWh)	Rate (%)	Quantity (TWh)	Rate (%)	Quantity (TWh)	Rate (%)	Quantity (TWh)	Rate (%)
Northeast China Grid Company	**Inner Mongolia (east)**	–	–	5.236	34.30%	3.399	19.54%	3.012	18.43%	–	–
	Liaoning	0.390	10.45%	1.129	12.54%	0.528	5.00%	0.780	7.00%	1.200	10.00%
	Jilin	0.475	21.02%	2.032	32.23%	1.572	21.79%	1.091	15.74%	2.700	32.00%
	Heilongjiang	0.448	14.39%	1.050	17.40%	1.151	14.61%	0.925	11.70%	1.900	21.00%
North China Grid Company Limited	**Hebei**	0.178	3.86%	1.765	12.48%	2.800	16.59%	2.322	13.68%	1.900	10.00%
Inner Mongolia Power(Group) Co., LTD	**Inner Mongolia (west)**	–	23.10%	6.099	26.03%	2.990	12.17%	2.680	10.54%	–	18.00%
Northwest China Grid Company Limited	**Gansu**	1.094	25.25%	3.024	24.34%	3.102	20.65%	1.386	10.77%	8.200	39.00%
	Xinjiang	0.070	5.20%	0.215	4.29%	0.431	5.23%	2.372	14.80%	7.000	32.00%
Overall of China		13.000	15.00%	20.822	17.12%	16.231	10.74%	14.884	7.90%	33.900	15.00%

Note on data sources
For 2011, the data were collected from the Chinese Wind Energy Association [21, p. 3, table 1] and figure 8.
For 2012, the data were collected from "2014 China wind power review and outlook" [20, p.40, table 2–9].
For 2013 and 2014, the data were collected from "Renewable energy data manual 2015" [2, p.141, table 4-28].
For 2015, the data were collected from National Energy Administration of China [19].
For the data of Inner Mongolia Autonomous Regions in 2011 and 2015, the total quantities of wind energy rejection including East Inner Mongolia and West Inner Mongolia were 3.290 TWh and 9.100 TWh respectively.

4.3.2. Status of selected provinces

In this section, wind energy rejection status of several typical and important provinces are given and discussed. Fig. 9 shows the ratio of the installed capacity of wind turbines of the selected provinces in China to the total capacity. Fig. 10 shows the map of the operational zones of the grid companies (referring to Sec. 4.2 and Tab. 9 for details). Based on the geographical locations, the provinces can be categorized into four groups i.e. west China (e.g. Xinjiang, Gansu), northeast China (e.g. Liaoning, Jilin, Heilongjiang, East Inner Mongolia), north China (e.g. Hebei) and others. Based on Fig. 9, one can find that the provinces of the west, northeast and north China occupy 61.05% of the total installed capacity of the wind turbines. At the same time, those provinces are currently suffering serious wind energy rejection problems. Hence, in this paper, the status and reasons for wind energy rejection in those provinces will be shown and discussed in great details. Another characteristic of the selected provinces discussed in this section is the low local power demand. For the provinces with high power demand, both the installed capacity of wind energy and seriousness of the wind energy rejection are limited. Therefore, cases of those provinces will not be discussed here.

Table 10 shows the details of quantity and the rate of the wind energy rejection in the selected provinces of China between 2010 and 2015. Up to the year of 2015, the accumulative total grid-connection installed capacity of the wind turbines is 129.34 GW, among which the provinces listed in the Table 10 occupy about 61.05% of the total grid-connection installed capacity (78.96 GW). For the details, readers are referred to Fig. 9. Based on Table 10, one can find that the wind energy rejection problem is very serious in China according to both the amount and the rate of the rejected electricity. For the past five years, the rejection rate of most provinces in Table 10 is above 10%. In the year of 2015, the rejection rate of Jilin province reaches a significant high level (32%). According to the data of October of 2015, the rejection rate of Heilongjiang province reaches 40%, leading to the rejection of 500 GWh electricity [22].

The total amount of the electricity due to the wind energy rejection in a single year is also prominent. It should be noted that in 2015, the total amount of the dropped electricity in China reaches 33.9 TWh (referring to Fig. 8), reaching the maximum of the historical data. Hence, one can find that the wind energy problem is becoming more and more serious in the recent and coming years.

5. Reasons for the wind energy rejection

5.1. The mismatch with the development of electric power grid

5.1.1. The over-construction of wind farms

In the 12th five-year plan [23] between 2010 and 2015, China's authority had made a detailed plan for the development of wind turbines and associated electric transmission lines. However, due to the various kinds of incentive mechanism (e.g. the tax reduction or exemption, electric price compensation) and policy issues (referring to Appendix F for details), the development of the wind farms in China is much more rapid than expected, leading to the mismatch with the original plan (e.g. in terms of matched local power demand and the electric transmission lines).

Table 11 compares the targets of the 12th five-year plan between 2010 and 2015 and the related data at the end of year 2015. According to this plan, the specific targets of wind energy development are: total installed capacity reaching 100 GW, total annual electricity generated by the wind energy reaching 190.00 TWh and the ratio of the electricity generate by the wind energy to the total generated electricity reaching 3.00%. However, at the end of 2015, the total installed capacity reaches 129.34 GW (129.34% of the target) with extra 87.07 GW under construction. This implies overheat of the wind farm constructions in terms of the overall total installed capacity.

A further example will be given based on the data of the provinces in China. Table 12 shows the current status of the wind energy development in several selected provinces. Comparing with the planned installed capacities according to the 12th five-year plan between 2010 and 2015 (as shown in the Table 12), many leading provinces of wind energy development have over-fulfilled the quota. Those provinces play an important role on the wind energy of China in terms of installed capacities (referring to Fig. 9). Hence, at the level of province, there also exist strong over-constructions of wind farms in many paramount provinces.

One of the underlying mechanisms for the fast development of the wind power in China is the incentive policy system. From 2005, the Chinese government had released a lot of policies to foster the development of the wind energy as listed in Table 13. Those policies covered a broad range of topics relating with the wind energy development. The paramount incentive mechanism can be categorized into three groups as follows: high electric price compensation, tax reduction or exemption, and priority for dispatch.

In this section, we will take high electric price compensation as an example. In China, the electric price of wind energy (also solar energy) is higher than the price of other kinds of energy (thermal or hydro). According to the policy "Temporary Policy for the Management of Renewable Energy Development Foundation" (released in 2011 by the Ministry of Finance of P. R. China and National Development and Reform Commission, China) and the policy "Temporary Policy for the Management of Electric Price Compensation of the Renewable Energies" (released in 2012 by the Ministry of Finance of P. R. China and National Development and Reform Commission, China), the electric grid could provide a higher price for the electricity of the wind energy than the price of the traditional energies. And, the difference between two could be covered by the Renewable Energy Development Foundation. Additionally, Renewable Energy Development Foundation could also cover the cost of the grid construction (for connections to the renewable energies) and other related fees.

Specifically, for the recent serious over-construction of the wind energy, the electric price adjustment plays a negative role. According to the policy "Notice for the Adjustment of the Standard Price of Wind Energy in the Grid" (released on Dec 31th, 2014 by the National Development and Reform Commission, China), the electric price of wind energy will decrease 0.02 RMB/kwh in the types I, II, III resource zones. This policy applies to the wind energy projects approved after Jan 1st 2015 or projects approved before Jan 1st 2015 but connection to the grid after Jan 1st 2016. Hence, in order to avoid the economic loss due to this policy, the wind energy company accelerated their construction process of the wind farm, serving as one of the reasons for the over-construction as discussed previously in this section.

There are also some policy issues for the over-construction of wind farms. In 2006, the government changed the approval process. If the capacity of the wind energy project is below 50 MW, the new policy gives the local governments the power for examination and approval of the projects. However, before this policy, those projects should be approved by the National Development and Reform Commission (NDRC), which usually involves the evaluation of the local power demand and the constructions of the transmission lines for the approval. In China, the local government could not decide the constructions of the transmission

Table 11
The planned targets of 12th five-year plan of China and the current status. The data of the targets of 12th five-year plan were collected from "The 12th five-year plan of wind power" [23, p.10]. The data of the current status up to the end of 2015 were collected from the National Energy Administration. For the projects under construction, readers are referred to the fifth approval capacity of 12th five-year plan in 2015 the released by the National Energy Administration [24].

Items	Grid-connected installed capacity (GW)	Electricity generation (TWh/year)	Ratio between wind and total (%)	Comments
Targets	100.00	190.00	3.00	–
Status	129.34	186.30	3.3	87.07 GW under construction [19]

Table 12
The targets and the current status of the 12th five-year plan of the selected provinces or autonomous regions. The data of the targets of the grid-connected wind turbines were collected from "12th five-year plan of wind power" [23, p. 13, table 2 and table 3]. The data of the current status were collected from the website of National Energy Administration [19].

Province/Autonomous region	Target (GW)	Current status (GW)	Completed Ratio (%)
Xinjiang	10.00	16.11	161.10%
Inner Mongolia	21.00[a]	24.25	115.48%
Gansu	11.00	12.52	113.82%
Liaoning	6.00	6.39	106.50%
Hebei	11.00	10.22	92.91%
Shandong	8.00	7.21	90.13%
Heilongjiang	6.00	5.03	83.83%
Jilin	6.00	4.44	74.00%
Jiangsu	6.00	4.12	68.67%

Note

[a] The target of the west and east Inner Mongolia are 13 GW and 8 GW respectively.

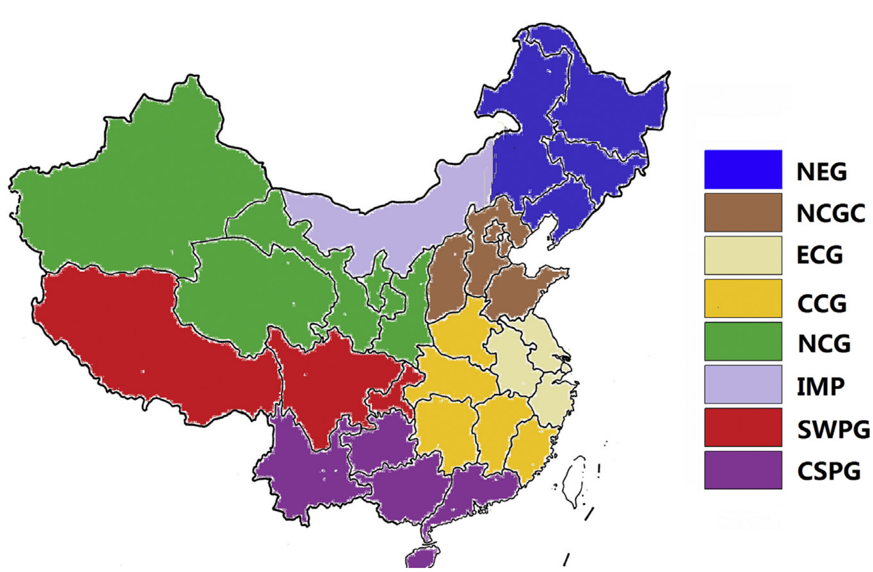

Fig. 10. The operational zones of the companies in the field of the electrical power grid in China. Marked labels are the abbreviation of the name of the operational companies as listed in the abbreviations.

Table 13
The laws and regulations in China relating with the renewable energies.

Date	Name of laws and regulations	Comments
Feb 2005	"Renewable energy law of the people's Republic of China"[a]	1. Creation of the Renewable Energy development Foundation; 2. Price of renewable energy management and compensation
Jan 2006	"Trial Measures for the generation prices and cost sharing of renewable energy power generation"[b]	1. Determination of the price of wind energy; 2. The price difference between wind and thermal energy will be covered through charging additional fees from consumers.
Jan 2006	"Regulations on the administration of renewable energy power generation"[c]	Capacity below 50 MW will be approved by the local government.
Aug 2007	"Regulations on the energy saving dispatch (trial version)"[d]	Priority of the renewable energy for dispatch.
Sep 2007	"Regulations on grid for the total absorption of the renewable energy electricity"[e]	Grid should buy all the electricity generated by renewable energies.
Dec 2008	"Circular on the comprehensive utilization of resources and other products' value added tax policy"[f].	Reduction of VAT 50% for the profit by selling the wind energy.
Jan 2008	Enterprise income tax law of the People's Republic of China rules for its implementation[g]	Wind energy companies will be exempted from the income tax for the initial three years and then will be charged 50% income tax for the next three years.
Jul 2009	"Circular on improving the electricity price policy of wind power"[h]	1. Definitions of the four zones with wind energies with setup of the wind energy electric price; 2. Regulations on the share of the fees involving wind energy.
Dec 2009	"Renewable energy law of the people's Republic of China"(Revision)[i]	The fourteenth item was revised together with the changes on the development plan of grid.
Nov 2011	"Notice on the pilot work plan and detailed instructions of the dispatch system for energy saving"[j]	Setup of the priorities for the dispatching renewable and clean energies.
May 2013	"Decisions on the cancellation or adjustment of the approval authorities of projects from the State Council"[k]	Local governments are empowered to approve the wind energy project

Notes
Parts of the table was modified based on Ref. [25, p. 13, table 3–1].

[a] was released by the State Council, China. Website: http://www.gov.cn/ziliao/flfg/2005–06/21/content_8275.htm.
[b] was released by the National Development and Reform Commission. http://www.gov.cn/ztzl/2006–01/20/content_165910.htm.
[c] was released by the National Development and Reform Commission. Website: http://www.sdpc.gov.cn/zcfb/zcfbtz/200602/t20060206_58735.html.
[d] was released by the State Council. Website: http://www.nea.gov.cn/2007–08/28/c_131053158.htm.
[e] was released by the State Electricity Regulatory Commission People's Republic of China. Website: http://www.gov.cn/ziliao/flfg/2007–08/01/content_702636.htm.
[f] was released by the State Administration of Taxation. Website: http://www.chinatax.gov.cn/n810341/n810755/c1226344/content.html.
[g] was released by the State Council, China. Website: http://www.gov.cn/zwgk/2007–12/11/content_830645.htm.
[h] was released by the National Development and Reform Commission. Website: http://www.sdpc.gov.cn/zcfb/zcfbtz/200907/t20090727_292827.html.
[i] was released by the State Council, China. http://www.gov.cn/fwxx/bw/gjdljgwyh/content_2263069.htm.
[j] was released by the National Energy Administration. Website: http://www.nea.gov.cn/2011–11/22/c_131262571.htm.
[k] was released by the State Council, China. Website: http://www.gov.cn/zwgk/2013–05/15/content_2403676.htm.

lines (referring to the Appendix A for details). Hence, the above change of policy leads to a mismatch between wind energy development and constructions of transmission lines, causing the great connection difficulties of wind energy to the grid [26, p. 64–65]. The negative effect of the released policy will be further discussed in Appendix F, which takes the Gansu province as an example.

5.1.2. *The construction of the electric grid*

Comparing with the constructions of wind farms, the required time for the construction of the electric grid (including transmission lines and transformer substation) is rather long. The required time for the process of the two kinds of projects (wind farm and electric grid respectively) is quite different. For the wind energy project, generally, the time required for the construction of the first unit of wind turbine is only six months and the time required for the complete wind farm is of the order of one year. For the construction of the electric power grid, the building time is much longer due to the multi-province co-operations and coordination. For example, the time required for building a 750 kV transmission line is over two years [27, p. 517].

Besides, the construction of the transmission lines of the electric power grid belongs to the infrastructure projects, which usually involve too many policy issues, uncertainties of the project profits and progress. As a result, the interest from the financial markets on constructing the transmission lines of the electric grid is limited [27, p. 517].

Hence, comparing with fast development of wind farms, the progress of the construction of the transmission lines is usually delayed, leading to the mismatch with the wind farm projects. Taking the wind farms in Kailu county located in the eastern part of Inner Mongolia as an example. According to the 12th five-year plan, the installed capacity of Kailu county will reach 3.25 GW [28] and a 500 kV transformer substation will be also built for the transmission of the generated electricity [29, p. 22]. In October of 2013, the 1.1 GW installed capacity of wind energy has been fulfilled in Kailu county with 0.6 GW approved [28]. However, the construction of the 500 kV transformer substation started in April of 2014, far behind the plan and also the development of the wind farm [30]. As a result, although parts of the wind energy could be transmitted through the nearby transformer substation (e.g. 500 kV transformer substation in Tongliao city and 220 kV transformer substation in the Kailu county), serious wind energy rejection events occurred [29, p. 22].

5.1.3. *Absence of the update of the plan*

Although the government has released many plans and targets for the renewable energies, the matched development of the electric grid is not updated with the rapid constructions of the wind farm. Due to various reasons (e.g. scientific demonstration and local interests), the necessary modifications on the plan of the electric grid has not been made yet in order to accommodate the fast development of the wind power [20, p. 68].

5.2. *Insufficient local adoptions of wind power*

5.2.1. *Low local power demand*

In China, the majority of the electrical power demand is from the east, middle and north China, where the economic development is fast with a large amount of industries. However, the

Table 14
The statistics of gross domestic production (GDP) and electric consumption of all the provinces in China. The GDP data were collected from the website of the National Energy Administration and the data of the electric consumption were collected from "China electric power yearbook 2014" [31, p.596].

Location	Province	GDP (Billion Chinese Yuan)	Ranking	Electric Consumption (TWh)
North East	Liaoning	2721.30	7	200.80
	Heilongjiang	1445.50	17	84.50
	Jilin	1304.60	21	65.40
North West	Xinjiang[a]	844.40	25	154.00
	Gansu	633.10	27	107.30
	Ningxia[a]	257.80	29	81.10
	Shaanxi	1604.50	16	115.20
	Qinghai	210.10	30	67.60
North China	Beijing	1980.10	13	91.30
	Tianjin	1444.20	19	77.40
	Hebei	2844.30	6	325.10
	Shanxi	1266.50	23	183.20
	Inner Mongolia[a]	1691.70	15	218.20
East China	Shandong	5523.00	3	408.30
	Jiangsu	5975.30	2	495.70
	Anhui	1922.90	14	152.80
	Zhejiang	3775.70	4	345.30
	Jiangxi	1441.00	20	94.70
	Fujian	2186.80	11	170.10
	Shanghai	2181.80	12	141.10
Middle of China	Henan	3219.10	5	289.90
	Hubei	2479.20	9	153.00
	Hunan	2462.20	10	142.30
South West	Yunnan	1183.20	24	146.00
	Guizhou	808.70	26	112.60
	Sichuan	2639.20	8	194.90
	Tibet[a]	81.60	31	3.10
	Chongqing	1278.30	22	81.30
South China	Guangdong	6247.50	1	483.00
	Guangxi[a]	1445.00	18	123.80
	Hainan	314.70	28	23.20

[a] Autonomous Region.

Table 15
Comparisons between the installed capacity and electric consumption in several selected provinces or autonomous regions with serious wind energy rejection problems. The data of 2013 were collected from "China electric power yearbook 2014" [31, p. 596, p. 599]. The data of 2012 were collected from "China electric power yearbook 2013" [33, p. 619, p. 621].

Province/Autonomous region	2012		2013	
	Increase[a] of Installed Capacity (%)	Increase[a] of Electric Consumption (%)	Increase[a] of Installed Capacity (%)	Increase[a] of Electric Consumption (%)
Hebei	9.37	3.11	7.24	5.63
Inner Mongolia	4.45	8.19	8.23	8.19
Liaoning	11.96	2.06	4.17	5.72
Jilin	4.05	1.09	4.95	2.64
Heilongjiang	4.09	3.25	10.12	2.09
Gansu	6.22	7.70	19.67	7.91
Xinjiang	38.08	37.23	44.11	33.72

[a] The data of increase shown here were obtained by dividing the value of the current year by one of previous year.

energy resources concentrate in the other parts of China (e.g. northeast and northwest of China, referring to Section 2.1), where the local electrical demand is very low. Table 14 shows the gross domestic product (GDP) and electric consumption of all of the provinces in China. The provinces have been categorized based on the geological locations for reader's convenience. Based on Table 14, comparing with the east China (e.g. Jiangsu and Zhejiang provinces), both the GDP and electric consumption in the northwest China are quite low. For example, in 2013, the GDP and electric consumption of Jiangsu province is 5975.3 billion Chinese Yuan and 495.7 TWh, which is 4.62 times of the electric consumption of Gansu province. Moreover, the electric demand in the provinces with rich energy resource is decreasing. The total electric consumption of the Jilin province from January to November of 2015 decreases 2.4% [32].

Another reason for the rejection of the wind energy is due to the quotation system of China, which belongs to the old-fashioned planned economics. In the current situation, the quotation will be issued to the traditional power plants (e.g. coal-fired ones) and wind farms could not obtain the quotations. When the local power demand is high, both the traditional energy and wind energy could connect to the grid if the safety can be guaranteed. When the local power demand is limited, the traditional power plants are of priority due to the quotation system. In the Appendix B, a detailed introduction of this quotation system is given together with some new trends on the quotation exchange policies.

Table 16
Installed capacity and rejected wind energy of wind energy in Heilongjiang province between 2010 and 2012. The data of installed capacity of wind power in 2010 were collected from "The statistic of installed capacity of China's wind power in 2010" [34, p. 36, table 1]. The data of installed capacity of wind energy in 2011 were collected from "The statistic of installed capacity of China's wind power in 2011" [35, p. 44, table 1]. The data of installed wind power capacity of wind energy in 2012 were collected from "The statistic of installed capacity of China's wind power in 2012" [36, p.47, figure 1, figure 2]. The data of connection capacity, rejection electricity, rejection rate and utilization of time between 2010 and 2012 were collected from the private communications with the State Grid Heilongjiang Electric Power Company Limited [37].

Parameters	2010	2011	2012
Total installed capacity (MW)	2370.1	3445.8	4264.4
New installed capacity (MW)	710.3	1,075.8	818.6
Increasing rate (%)	42.80%	45.39%	23.76%
Grid connection capacity (MW)	1910.0	2550.0	3230.0
Rejected electricity (TWh)	0.293	0.728	0.912
Rejection rate (%)	8.14%	14.21%	15.09%
Utilization of time (h)	2031	1970	1780

5.2.2. Rapid increase of the total installed capacity

The increase of the total installed capacity (including all types of energies) is very significant. Table 15 shows the comparisons of the increase rate of the installed capacity and electric demand of the selected provinces (with serious wind energy rejections) in 2012 and 2013 respectively. It can be found that in the most provinces, the increase rate of the installed capacity is far beyond one of the electric demand. For example, in 2012, the increase rate of the installed capacity in Liaoning province is 11.96% while the increase rate of the electric demand is only 2.06%.

Now, we take Heilongjiang province as an example. In Heilongjiang province, the increase rate of the wind power is also significant as shown in Table 16. However, serious wind energy rejection occurred due to rapid increase of the total installed capacity. Between 2010 and 2012, the total installed capacity increased from 2370.1 MW to 4264.4 MW (30% increment per year) while the electricity demand only show 7% increment per year.

5.3. Insufficient exchange of electricity among provinces

5.3.1. Immature system without clear policies

Currently, the electricity exchange market of China is rather immature in terms of the policies (e.g. price, freedom, and

Table 17
The power grids cross provinces in China (excluding ultra-high voltage lines) up to the 2013. The table was collected from Ref. [47].

Send side	Receive side	Interconnected Power Grid	Comments
INNER Mongolia Power(Group) Co., LTD	Mongolia	220 kV and 110 kV transmission lines	–
Shanxi Yangcheng power plant (North China Grid Company Limited)	East China Grid Corporation	500 kV AC	Point to network
Central China Grid Company Limited	East China Grid Corporation	500 kV Gezhouba-Shang-hainanqiao DC	Gezhouba hydropower station
Central China Grid Company Limited	East China Grid Corporation	± 500 kV Longquan-Zhengping DC	–
Central China Grid Company Limited	East China Grid Corporation	500 kV Yichang-Huaxin DC	–
Central China Grid Company Limited	East China Grid Corporation	± 500 kV Lifeng DC	Three Gorges hydropower station:3 GW
Liyujiang hydropower station of Hunan province (Central China Grid Company Limited)	Guangdong Grid Company (China Southern Power Grid Company Limited)	500 kV AC	Point to network
Northwest China Grid Company Limited	Central China Grid Company Limited	Lingbao Back-to- Back	Rated power is 0.75 GW
Northwest China Grid Company Limited	Central China Grid Company Limited	± 500 kV Debao DC	Design rated power:3 GW, Actual rated power:1.5 GW
Northwest China Grid Company Limited	Tibet Power Grid	± 400 kV Geermu-Lasa DC	–
Northwest China Grid Company Limited	North China Grid Company Limited	± 660 kV Ningdong-Shandong DC	–
Fugu and Jinie power plants in Shanxi province (Northwest China Grid Company Limited)	North China Grid Company Limited	500 kV AC	Point to network; connection with South of Hebei grid Company (North China Grid Company Limited)
Northeast China Grid Company	Russia	Heihe Back-to- Back DC	International power exchange
Northeast China Grid Company	North China Grid Company Limited	Gaoling Back-to-Back DC	Rated power is 3 GW.
China Southern Power Grid Company Limited	Central China Grid Company Limited	± 500 kV Jiangling-echeng DC transmission lines	–
China Southern Power Grid Company Limited	Hong kong, Macau	AC lines	–
China Southern Power Grid Company Limited	Vietnam, Burma, Laos, etc. south-east Asian countries	220 kV and 110 kV AC lines	–

approval). For example, the price of the electricity is still not flexible and needs the approval of the government. A reasonable price is a key parameter to foster the electricity exchange among different provinces. At current status, the majority of the extra wind energy could still not be transmitted to the nearby provinces even those provinces shows the electricity demand [38, p. 1–2, p.6–7].

5.3.2. Shortage of the electricity transmission lines

The wind energy mainly locates in the northeast, northwest and northern parts of China while above two third of the energy demand concentrates in the middle and east China. Generally, the geological distance between those energy generation sites and the demand center is about 300–3000 km [39, p.4]. Currently, there is still insufficient electricity transmission lines between the two sides. Table 17 shows the power grid cross provinces in China (excluding ultra-high voltage lines) by the end of 2013. Based on Table 17, the electricity transmission lines among different power grids are still insufficient in terms of numbers and abilities.

In order to foster the electricity exchange in a long distance, ultra-high voltage (UHV) electricity transmission lines are being widely built in China. Table 18 shows the current ultra-high voltage electricity transmission lines in China. Based on the Table 18, the total transmission ability reaches up to 46.1 GW by the end of 2015. However, there are a few electricity transmission lines for transmitting the electricity produced by wind turbines. Furthermore, currently, there is no available UHV in northeast China where wind energy is rich.

5.3.3. Electricity surplus in the surrounding provinces

Around the provinces with prominent wind energy rejection, there exists electricity surplus in the surrounding provinces, leading to the difficulties in the wind energy transmission cross provinces. For example, up to 2015, the rejected electricity of wind energy in Heilongjiang province reaches 1.9 TWh with the rejection rate 21% [19, p.1]. Meanwhile, the surrounding provinces of Heilongjiang province (e.g. Liaoning, Jilin, Inner Mongolia Autonomous Region) also suffer great wind energy rejection problems. For example, in Liaoning province, Hongyanhe nuclear power station was commissioned at the end of the year 2014, consisting four units with each 1.118 GW and the generated electricity in one year exceeding 30 TWh [48]. Hence, in the year of 2015, the rejected electricity of wind turbines in Liaoning province reached 1.2 TWh with the rejection rate 10% [19, p.1].

5.4. Unreasonable structure of the electric power system

Fig. 11 shows the structure of the electricity providing system of China up to the end of the year 2014. In China, the resource of coal is rich while the resources of oil and natural gas are limited. Hence, the coal-fired power plants play a dominant role on the electric power system [49, p. 3]. According to the revealed data [50], the installed capacity of the thermal power plants occupies 65.62% of the total capacity. And, 75.43% of the electricity in China is generated by the thermal power plants. Among the thermal power plants, coal-fired power plants are the majority (93.06%). However, the flexible units (e.g. oil-fired power plants, gas turbines and energy storage power plants) are very limited in China. In the following sections, the current status of the flexible units in China will be briefly discussed.

5.4.1. Limited capacities of flexible units

Based on Fig. 11, the installed capacities of gas turbines and oil-fired power plants are 56.97 GW and 5.12 GW respectively (4.18% and 0.38% of the total installed capacity). Fig. 12 shows the data of the flexible units in China between 2010 and 2014. During 2010–2014, the ratio of the installed capacity of gas turbines is increasing slightly while ratio of the oil-fired power plants is decreasing.

In order to shaving the peaks, currently, the coal-fired power

Table 18
The transmission lines of ultra-high voltage (UHV) in China. The data were collected from the websites [40–46].

Name	Voltage (kV)	Rated power (GW)	Across provinces	Main type of transport power
Jindongnan–Nanyang–Jingmen UHV AC experimental example project [40]	1000	5.0	Connected North China power grid with Central China power grid; Shanxi, Henan, Hubei	Coal-fired: From North China to Central China Hydropower: From Southeast and Central China to North China
Zhebei-Fuzhou UHV AC transmission trial project[41]	1000	Recently: 6.8; Forward: 10.5	Zhejiang, Fujian	Promote the ability of accepting external power and optimal allocation of resources in the area of East China power grid.
The Huainan-Shanghai UHV AC transmission trial project[42]	1000	4.1	Anhui, Zhejiang, Jiangsu, Shanghai	Promote the ability of accepting external power of East China power grid.
Haminan-Zhengzhou UHV DC transmission trial project[43]	±800	8.0	Xinjiang, Gansu, Ningxia, Shaanxi, Shanxi, Henan	Wind power together with coal-fired: From Northwest to Central China
Xiangjiaba-Shanghai UHV DC transmission trial example project[44]	±800	7.0	Sichuan, Chongqing, Hunan, Hubei, Anhui, Zhejiang, Jiangsu, Shanghai	Hydropower: From Southwest to East China
Jinping-Sunan UHV DC transmission trial project[45]	±800	7.2	Sichuan, Yunnan, Chongqing, Hunan, Hubei, Zhejiang, Anhui, Jiangsu	Hydropower: From Southwest to East China
Xiluoduzuoan-Zhejiangjinhua UHV DC transmission trial project[46]	±800	8.0	Sichuan, Guizhou, Jiangxi, Hunan, Zhejiang	Hydropower: From Southwest to East China

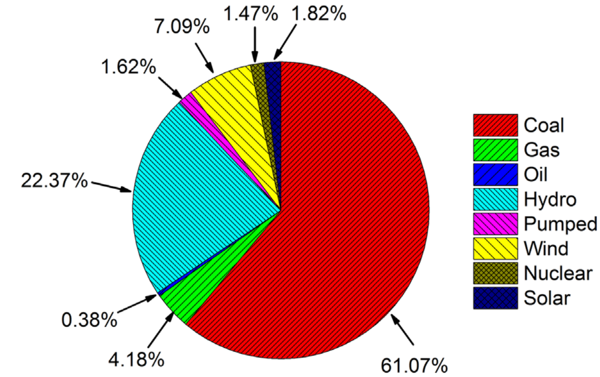

Fig. 11. The ratio of the installed capacity of different electricity supply units in China up to 2014. The data were collected from China Electricity Council [50].

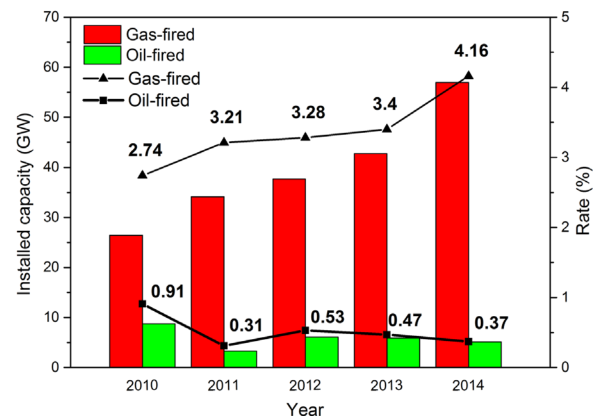

Fig. 12. The development of peak shaving power stations (oil-fired and gas-fired units) in China between 2010 and 2014. The red columns represent the installed capacity of the gas-fired units and the green columns represent the installed capacity of the oil-fired units. The two lines represent the rates of the installed capacity of oil-fired and gas-fired units to total installed capacity. The data between 2010 and 2011 were collected from "List of statistics basic data of electric power industry in 2011" by China Electricity Council. The data between 2012 and 2013 were collected from "List of statistics basic data of electric power industry in 2013" by China Electricity Council. The data of 2014 were collected from "List of statistics basic data of electric power industry in 2014" by China Electricity Council.

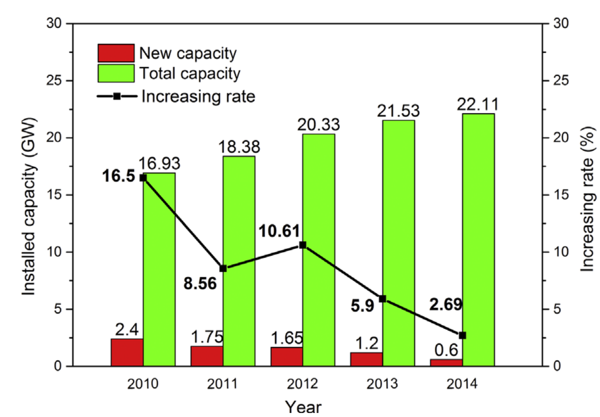

Fig. 13. The development of pumped hydro energy storage power plants (PHESPPs) in China. The data were collected from the basic data of the electric power between 2010 and 2014 released by China Electricity Council (Website: http://www.cec.org.cn/guihuayutongji/tongjxinxi). The data of the new installed capacity in 2010 was deduced based on Ref. [54, p.423].

plants are being required to be operated at conditions far away from the design point. Generally speaking, the flexible operational regions of the coal-fired power plants are very limited. Most units in China can only be operated above 50% of the rated power while several advanced units in Germany could reach 40% of the rated power. The adjustment speed is also quite slow (1–2% per min) [51, p.5386–5387]. The frequent operation in the off-design condition could also lead to the increase of coal consumption and pollutions and also the safety problems of systems (e.g. damage of the components) [49,52]. For example, if the system is operated at the 50% of full load, the fired coal will increase 14% [27, p.518]. For a detailed review of the above issue, readers are referred to Gu et al. [53].

Similarly, large-scale hydro turbines could also be operated in off-design conditions to shave the peaks. In China, most hydro turbines locate in the southwest of China, where the demand of the electricity is limited. Furthermore, in order to fulfill the irrigation and the control of flood, the hydro turbines are not being widely employed for the peak shaving [11, p.239,49 p.2,54, p.421].

5.4.2. Absence of the large-scale energy storage units

Pumped hydro energy storage power plant (PHESPP) is currently being widely employed for compensating the fluctuations in the electric power grid caused by the renewable energies worldwide [55,56] e.g. USA [57], India [58], Greek [59], Turkey [60], and isolated islands [61]. For the development of PHESPP in China, readers are referred to Zeng et al. [62]. The PHESPP is of many advantages e.g. peak shaving, valley filling, backup, and black start. Fig. 13 shows the development of PHESPP in China. Up to the end of 2014, the installed capacity of the PHESPP is 22.11 GW (1.61% of the total) [50]. However, there are still great gaps to ensure the power grid stability when a large amount of wind energy are connected to the power system. Furthermore, the current PHESPPs suffer great flow induced instability problems [63–67] (e.g. S-shaped instability [66,67] and rotating stall [64]) and vibrations [68].

5.5. Influence of heating supply in winter

As shown in Section 2.1, northeast China is rich of the wind energy. During the winter, the temperature is very low in those regions and hence the ratio of the coal-fired power plants will increase in order to supply heat for the local people [69]. For example, the installed capacity of coal-fired units is 7.09 GW (86.82% of the total) in Hulun Buir of Inner Mongolia with the installed capacity of wind turbine being 0.76 GW (9.33% of the total) [70]. The duration of heat-supply in winter in some regions could reach as long as eight months. During this time, heat-supply units are all operated with full load if possible with great priorities. As a result, to ensure the stable operations of the coal-fired heat-supply units, wind energy must be rejected absolutely in most cases.

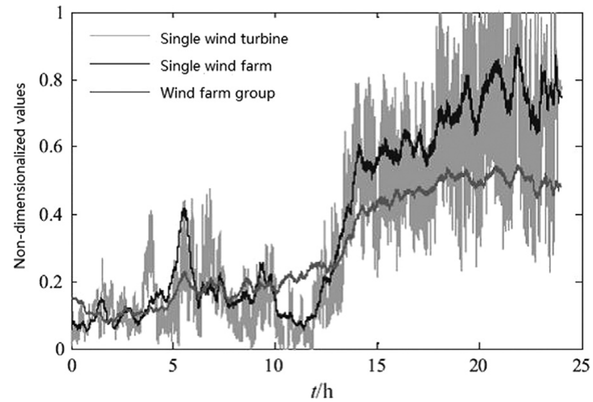

Fig. 14. Comparisons of output power between single wind turbine, single wind farm and wind farm group within the same time scales. The figure was adapted from Ref. [11, p.227, figure 5–2].

6. Solutions and perspectives

6.1. General picture

The seriousness of the wind energy rejection problems has attracted great attention from both the government and industries. Table 19 summarizes the related recent policies toward solving or relieving this problem. The suggested solutions can be categorized into three groups, energy generation side, electric grid side and demand side, the details of which will be given in the following sections.

6.2. Energy generation side

6.2.1. Roadmaps for the wind energy development

According to the recent policy [71], the wind energy will be developed mainly through two ways: large-scale wind farms and distributed small turbines. Figs. 14 and 15 show the fluctuations of the output power in different scales of wind farms. One can find that with the increase of the scale, the fluctuation of the output power will decrease. Hence, nine large-scale wind energy bases have been proposed with each of them of the order of tens of GW (in terms of installed capacity). This way will be employed in the regions with rich energy resources.

Another way is to develop the distributed system to incorporate small-scale wind turbines in the regions of the high energy demand (e.g. middle and east China) [23,77–79]. In order to foster the distributed (or hybrid) system, the government has

Table 19
The policies and guidance on the development of wind power in China. The data were collected from National Energy Administration [71–76].

Name	Date	Targeted problems
Notice of National Energy Administration on the guidance of energy development in 2014 [71]	Jan 2014	Patterns of development; transmission; consumption of wind power; construction of wind energy bases with supporting grids
Energy industry on strengthening prevention and control of atmospheric pollution [72]	May 2014	Construction of 12 power transmission channels; gas fired power station; wind energy bases; construction of power grid projects; distributed wind power; adoption of renewable energy locally
Opinions of National Development and Reform Commission on promoting the healthy and orderly development of pumped storage power station [73]	Nov 2014	Large-scale energy storage station
Guidance on promoting the development of the smart grid [74]	July 2015	Smart grid
Notice on the promotion of the wind energy heat-supply projects [75]	Mar 2013	Wind power heat-supply projects
Notice on integration and adoption of wind power in 2015 [76]	Mar 2015	Wind power integration and adoption; power system peak adjustment ability; compensation mechanism of the auxiliary service; hydrogen production by wind power

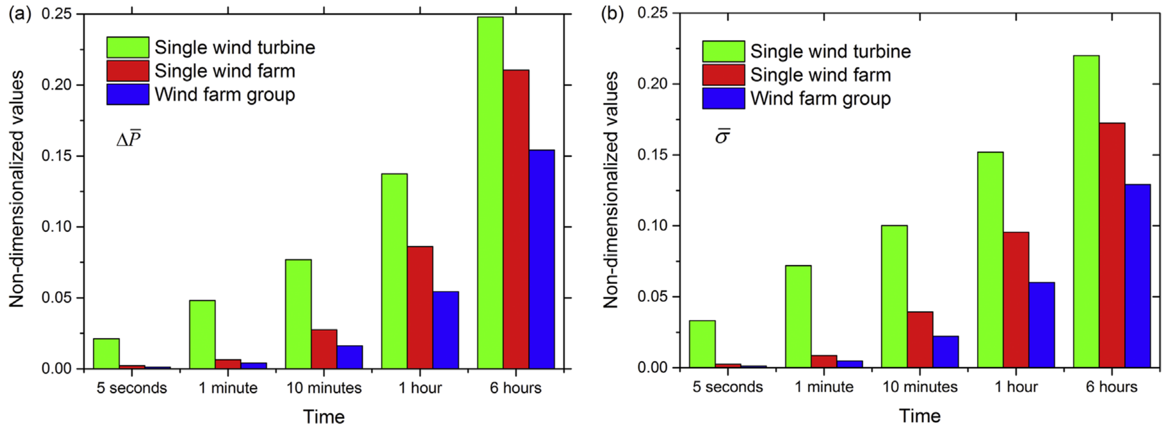

Fig. 15. The fluctuations of output power of single wind turbine, single wind farm and wind farm group within different time scales. The data were collected from [11, p.228, figure 5–3, tables 5–2]. Subplots (a) and (b) refer to the non-dimensional fluctuation of the active power ($\Delta\bar{P}$) and related standard deviation ($\bar{\sigma}$) respectively.

released a series of policies [23,78,79]. In the hybrid system, the wind turbine will be co-operated with other energy-supply system (e.g. solar energy, oil-fired turbines) in order to stabilize the grid [49, p.3]. In the year of 2015, the first project of the wind-solar-thermal hybrid system has been commissioned in Xinjiang Autonomous Region [80].

6.2.2. Peak shaving units

In recent years, wind energy has been developed rapidly in China (referring to Section 2.2). Due to the characteristics of the wind energy as shown in Section 3, this poses great challenges on the stability of the power grid. As a result, the coal-fired power plants are being required to shave the peak. Because China's power structure is based on the coal-fired units, further development of the techniques for great flexibility of those plants is of great importance [27,51,53]. The coal-fired power plants will undertake more peak shaving tasks for a long time in China. To ensure the safety of the power supply and solve the peak shaving problem, China has released some policies to encourage coal-fired units to be more and more involved in the load variations [53, p.729].

Gas-fired turbines are ideal for the peak shaving. However, due to the limited resources of the natural gases, the total installed capacity of gas-fired turbines is still very limited and their development is slow. According to the recent policies [71,72], the development of the gas-fired turbines is being speed up.

6.2.3. Energy storage power plants

According to the government policy, the construction of the pumped hydro energy storage power plant (PHESPP) in the large-scale wind energy bases is of priority. Chinese government has made a clear policy for the development of the PHESPPs [73]. The storage capacity of PHESPP is very large (up to 400 MW for a single unit), which can relieve the fluctuation of output power of wind energy and enhance the stability of the power grid. At the same time, the economy of transmission lines could also be improved [54]. According to the plan of government, in 2025, the total installed capacity of PHESPPs reaches 100 GW (4% of the total) with significant improvement of the relating systems (e.g. management system, price, technical and economic issues of PHESPP). According to ref. [81], recently, three PHESPPs of State Grid Corporation of China began to construct including Fengning (the second phase project) in Hebei province, Wendeng in Shandong province, Panlong in Chongqing Municipality . The installed capacity of Fengning power plant including the first phase and the second phase could reach 3.6 GW, and it will be the largest PHESPP all over the world.

6.2.4. Wind power prediction

The wind power prediction system is an obligatory requirement for the commission of the wind farms [82]. According to the current policy [82], the permitted maximum error of the daily prediction should be within 25% with the root-mean-square error smaller than 20%. The functions of the wind power prediction system have been also regulated in a recent policy [83]. According to the road map to 2050 [9, p.54], the super-short term (within 4 h) and the short term (within 48 h) prediction system should be fulfilled in 2015. In 2020–2030, the middle and long term (in terms of months or over) predictions should be developed [9, p.54].

The current prediction methods for wind power adopted by China include physical method and statistical method. The physical method is based on the numerical weather predictions, which is quite difficult in long term with great complexity. The statistical method requires a large amount of the history data and related data mining techniques for the analysis. Therefore, the present accuracy for the predictions of the wind power is very limited in China.

Currently, there is no penalty for the wind farm with large errors of wind power prediction in China. Although many policies have been made to regulate the predictions, no related punishment is actually executed to improve the enforcement of the policy. The reasons for this include lack of the national standard for the prediction accuracy, poor communications between grid and wind farms, and no regular release of the data. In fact, the predictions are quite essential to relieve the wind energy rejection as shown in some countries. For example, in Spain, if the error of the predictions exceeds a limit (e.g. 20%), the company will be fined.

6.3. Grid side

6.3.1. Constructions of ultra-high voltage grids

According to ref. [84], the rated power of south of Hami-to-Zhengzhou AC ultra high voltage (UHV) is 8 GW. It can transport 5 GWh electricity per year to central grid of China, equaling to the electricity generated by 2,300 million tons of coal. According to the current policy [72], in order to enlarge the scale of north-to-south power transmission and west-to-east power transmission, twelve electricity transmission lines will be constructed.

Fig. 16 shows a future map of the electric transmission lines with UHV lines. Based on this plan [9, p.60], the UHV grid system in China consists of four sub-grids: core grid (including north, middle and east China grids), northeast China grid, south China grid and northwest China grid. In the core grid, the 1100 kV extra high voltage transmission lines will be constructed in order to enhance the ability of energy exchange. Through this grid system, the wind energy generated in the northeast and northwest China

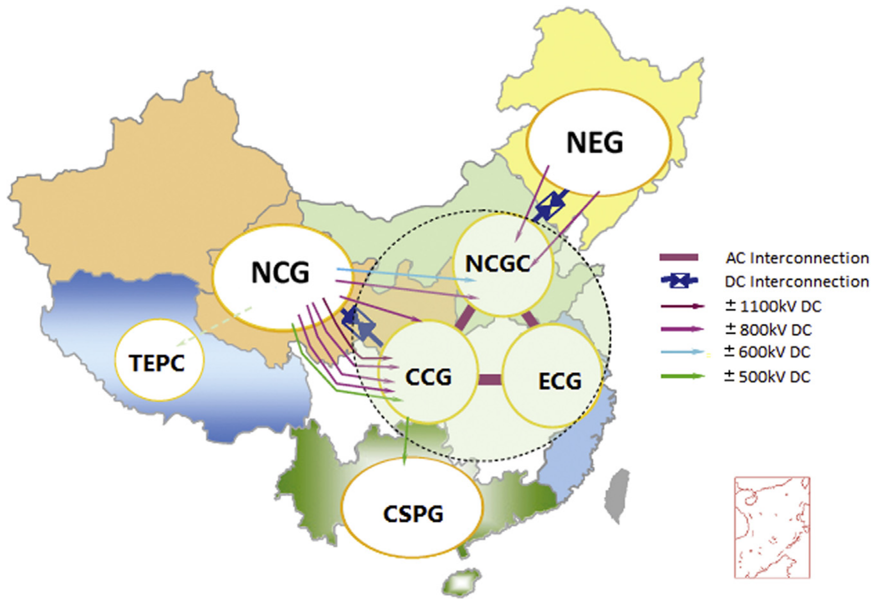

Fig. 16. The future plan for the interconnections of electric transmission lines between electrical sub-grids in China. The figure was adapted from "China Wind Roadmap 2050" [9, p.60].

could be transmitted to the core grid.

6.3.2. *Smart grid*

The smart grid has many advantages, e.g. open, convenience for energy exchange, clean and high efficiency [74,85]. According to the plan [74], the penetration level of wind energy could be enhanced through providing more flexibilities for the wind energy incorporations into the smart grid.

State Grid Company of China had released a series of reports for promoting the smart grid e.g. "General report on the intelligent planning of national power grid (revised)" and another seven special research reports (covering power generation, transmission, transformer, consuming, dispatching and communication in the smart grid). According to the report, strong smart grid can incorporate large-scale clean energy into the power grid and promote the rapid development of distributed energy. At the same time, it will also enable the access of more energy storage devices to the power grid. In the report, the transmission efficiency will be improved with the promotion of the exploration and utilization of wind and other clean energies.

6.4. *Demand side*

6.4.1. *Heat-supply units using wind energy*

For relieving the wind energy rejection problem, extra wind energy are being employed for heat-supply units [86,87]. For example, the Taonan wind power heat-supply project in Jilin province could consume 27 GWh of (rejected) wind energy within a single heat-supply period (176 days) [88]. In order to enhance the usage of the wind energy, many similar heat-supply projects have been commissioned. Up to the end of the year 2015, there are twenty projects approved in total with nine projects in Inner Mongolia Autonomous Region, eight in Jilin province, one in Shanxi province, and two in Xinjiang Autonomous Region [89–94]. For example, in Inner Mongolia Autonomous Region, the wind energy heat-supply area covers 1.6 million m^2 with 250 GWh wind energy consumed [89]. Because the wind energy heat-supply unit is an electric method, its cost is higher than one using coal-fired method (referring to Appendix C). Furthermore, the existing policies and institutions can hardly provide a strong incentive for the investment. Unless the significant reduction of the cost of wind energy, the wind energy heat-supply units are still not economical [86,95]. Hence, although several projects have been commissioned with many others approved, this issue is still under fierce debates in China. For more details about wind energy heat-supply projects, readers are referred to Appendix C for a complete list and discussions.

6.4.2. *Increment of industry with high electricity demand*

In order to increase the local energy demand, the Chinese government has made a new policy to foster the development of industries with high electricity demand e.g. hydrogen generation [76]. The first project of producing hydrogen using wind energy was settled in Hebei province. At present, there are two major problems (cost and transportation) for the further promotion of this kind of project [96]. Other types of industries (e.g. metallurgical industry of nonferrous metals) are also of great interest to the local government with serious wind energy rejection rate [27].

Take the Guyuan project in Hebei province as an example. This ongoing project will use the wind energy to generate hydrogen through the electrolysis of water to avoid the rejection of wind energy. The capacity of the project is 10 MW with 17,520,000 m^3 hydrogen production every year. The nearby wind farm is of the capacity 200 MW. This project will also be the world largest project of this kind of technique. The paramount factors on the economic aspect of this project include the electricity price and the hydrogen price. For more details, readers are referred to Appendix D.

7. Conclusions

In this review, a detailed analysis of the wind energy rejection problem in China has been performed with several solutions suggested and perspectives. Specifically, two case studies (Inner Mongolia Autonomous Region and Gansu province respectively) are provided in Appendix E and F. Due to its seriousness, wind energy rejection problem has attracted great attentions from the government with many policies released recently for relieving the negative impacts. For a thorough solution of the wind energy rejection problem, it requires the efforts of the whole society with the development of many advanced techniques (e.g. ultra-high voltage grids, energy storage system, and smart grid).

As China is one of the leading countries on the wind energy development in terms of installed capacity, the discussions shown in this review is representative and informative to other countries for making policies of the development of the renewable energies. Specifically, for the developing countries, the lessons could be learned from China include:

1. Appropriate approval of the wind energy projects. In order to foster the wind energy development, the Chinese central government empowered the local authorities (e.g. in the province) to approve the wind energy project with capacity smaller than 50 MW in 2006. Therefore, the central government loses its control of the wind energy development because the local authorities separate the large wind energy projects (e.g. above 50 MW) into several small ones (e.g. below 50 MW) to avoid the approval of the central government (referring to Appendix F). The negative effects of this is critical and serious. For example, during the approval of the new wind energy project by the local government authorities, there is no rigorous plan for the sufficient local consumption of the generated wind energy or the transmission lines for the wind energy transfer.
2. Cautions for establishing the related laws and policies. On the one hand, the laws should be made according to actual conditions. For example, in 2006, The Renewable Energy Law were released in China. According to this law, the electricity generated by the wind energy (or other renewable energies) should be all connected to the grid. However, due to various reasons, this law can not be exactly executed. Another example is a policy on the adjustment of the electricity price of wind energy (as shown in Section 5.1.1 with details). This policy leads to the abnormal constructions of the wind energy projects during 2015, which serves as one of reasons for the wind energy rejection of the year. Other examples include the policy on the wind power predictions (referring to Section 6.2.4).

Currently, serious solar energy rejection has been also reported in China (especially in Xinjiang Autonomous Region) and the reasons for this phenomenon also share some similarities with those shown in this review. As shown in Fig. 11, the ratio of the installed capacity of solar energy to the total capacity is 0.38% with a rapid increase rate. Hence, parts of this review can also be employed for the discussions of other types of the development of renewable energies (e.g. solar energy) in China.

In order to regulate the wind energy development, on the date July 18th 2016, the National Energy Administration released a new policy “Note on the establishment of the monitoring system for the proper development of the wind energy industry” (document number 2016-196). In this new policy, a monitoring system on the wind energy investment is established to regulate the related activities. Based on the current status in a certain province (e.g. local policy, energy resources, wind energy rejection status), all the provinces will be categorized into three classes (red, orange or green respectively) and the monitoring results will be released annually. For the province in the red class (e.g. Jilin, Heilongjiang, Gansu, Ningxia, Xinjiang in the year 2016) referring to the high risky investment, the approval of the new wind energy project will be prohibited in the coming year and the grid connection applications of the new wind energy projects will be also rejected by the grid company. For the province in the orange class (e.g. North Hebei, West and East Inner Mongolia in the year of 2016) referring to the medium risky investment, the annual development planning will not be issued by the National Energy Administration in this year. For the province in the green class, the situation is normal and wind energy investment is encouraged. Hence, with this strict rule, the over-construction of the wind farms will be relived significantly in the near future.

Acknowledgment

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Appendix A. A brief introduction of China's wind energy system

In this section, a brief introduction of the China's wind energy system will be given with a short description of the rules.

Investment on wind energy

The foreign or local economic organizations together with the individuals are all welcomed to invest on the wind energy. This right is guaranteed by the Electricity Law (P. R. China) and Renewable Energy Law (P. R. China).

Grid construction for renewable energies

Generally, the transmission lines for connecting renewable energies to the grid should be constructed and operated by the grid company. For the large or medium renewable energy projects (which will be connected to the power transmission network), in principle, the connection systems should be invested by the grid companies (only two companies, State Grid and China Southern Grid). For small renewable energy projects (which will be connected to the power distribution network), the renewable energy company (or individuals) could also be involved into the construction of the connection system with the agreement of the grid company. Therefore, the grid companies play a dominant role on the construction and management of the connection systems between renewable energies and the power grid.

Connections of electricity generated by the wind energy to the grid

The grid companies own the electricity transmission systems and are responsible for the related management issues. Specifically if the wind energy company wish to transmit their electricity to the grid, they must sign an agreement with the grid companies. Additionally, there are some extra national standards or industrial standards (referring to Section 4.2 for details) to be followed in order to avoid the negative impacts of the fluctuations of wind energy on the grid.

Price of the electricity generated by wind energy

Principally, this price is setup by the central government (e.g. State Council, China). The electricity price of wind energy is higher than ones generated by the traditional ways (e.g. thermal). For details of those policies, readers are referred to Table 13.

Appendix B. Routes for the connections of the wind energy to the grid

In the current status, the electric power system of China is still based on a planned economy system. Specifically, the grid company will make a plan for electricity generation for all the power stations within its management regions. As a result, the traditional thermal power station (serving as the dominant energy generation type in China) could obtain the quotation to ensure their connections to the grid. However, for the wind energy company, it could be difficult or even impossible to obtain the quotation for electricity transmission to the grid. The situation will be further deteriorated due to the protections of local government on the thermal power plants, which could contribute more tax and serve as the base load.

In some provinces (e.g. Gansu province), the local government tried to facilitate the exchange of the above quotations between wind energy companies and thermal power plants. Table 20 summarizes recent quotation exchanges between renewable energy companies and thermal power plants.

Basically, the subsidy from the government for the wind energy companies is calculated based on the amount of the generation of electricity. If no electricity is generated (e.g. during wind energy rejection), those subsidies (together with the electricity selling income) could not be obtained by the wind energy companies. In order to avoid rejection, the wind energy company needs the electricity quotations for the connections to the grid. Hence, under the support of the local government's policies, some thermal power plants could transfer their electricity quotations to the wind energy companies. For the thermal power plants, they could be profitable from the electricity price difference between the grid and the wind energy companies. During the exchange of quotation, the thermal power plants do not need to generate the

Table 20
A list of quotation exchange event between wind farms and coal-fired power plants.

Grids	Range	Time[a]	Transaction[b] (GWh)	Company involved
East Inner Mongolia[c,d]	In province	Oct.2012	0.03	1 wind farm and 1 power plant
Gansu[c,d]	In province	Sept.2015	650.00	138 renewable energy companies and 1 self-supply power plant
Gansu[e,f]	In province	Sept.2015	630.00	85 renewable energy companies and 1 self-supply power plant
Northwest China[g]	Inter-provinces	Dec.2014	50.75	Wind power plants in Gansu and Coal power plants in Shaanxi
Central China and Northwest China[h]	Inter-grid	Dec.2015	200.00	8 wind power plants of Gansu; 4 photovoltaic power plants; 2 power plants of Central China Grid Corporation

[a] The time shown here is the time of the released news.
[b] This is the cumulative quantities of the electricity transaction involved in a single contract.
[c] Website: http://www.chinanews.com/ny/2012/10–17/4256110.shtml.
[d] Related policy" Interim Measures for Wind-Coal alternative trading in Eastern Mongolia".
[e] Website: http://www.sdpc.gov.cn/dffgwdt/201509/t20150902_750020.html.
[f] Related policy" Interim Measures for Renewable energy and Coal power alternative trading across provinces in Northwest China Grid Company Limited".
[g] Website: http://www.cpnn.com.cn/zdzg/201501/t20150109_776796.html.
[h] Website: http://shoudian.bjx.com.cn/html/20160104/697630.shtml.

Table 21
A list of wind energy heat-supply projects.

Location	Time	Status	Heating Area (m^2)	Wind farm capacity (MW)	Electric boiler capacity (MW)
Taonan Jilin province (1st)[a]	Dec.2011	Commission	163,000	–	–
Faku Liaoning[b]	2015	Commission	200,000	–	–
Zhangbei Hebei[c]	Oct.2015	Commission	140,000	–	–
Hebei Institute Of Architecture And Civil Engineering[c]	Oct.2015	Commission	400,000	–	–
Yumen Gansu[d]	Jun.2012	Approved	–	–	–
Balinzuoqi Inner Mongolia[e, [p.28]]	–	–	60,000	49.5	12.96
Linxi County Inner Mongolia[f]	Nov.2013	Commission	920,000	–	–
Siziwang Banner Inner Mongolia[g]	Oct.2014	Commission	500,000	200.0	51.84
Ulanqab Inner Mongolia[h]	Mar.2012	Commission	120,000	400.0	–
Sonid Right Banner Inner Mongolia[i]	Dec.2011	Commission	5,000	–	–
Jarud Banner in Inner Mongolia (1st)[j]	Nov.2013	Commission	401,000	500.0	–
Linqiu County Shanxi[k]	Dec.2015	Approved	800,000	400.0	–
Altay City Xinjiang[l]	May 2016	In progress	100,000	–	–
Burqin County Xinjiang (1st)[m]	Jul.2015	In progress	100,000	–	–

[a] Website: http://jlrbszb.chinajilin.com.cn/html/2012–02/09/content_29410.htm? div= – 1.
[b] Website: http://www.cec.org.cn/hangyeguangjiao/lvsenengyuan/2013–05-15/102266.html.
[c] Website: http://www.escn.com.cn/news/show-252915.html.
[d] Website: http://www.gscn.com.cn/economic/system/2012/06/27/010113501.shtml.
[e] For details, readers are referred to ref. [29].
[f] Website: http://www.cec.org.cn/hangyeguangjiao/gongchengjianshe/2013–11-22/112608.html.
[g] For details, readers are referred to ref. [98].
[h] Website: http://www.cpnn.com.cn/zdzg/201403/t20140311_661040.html.
[i] Website: http://szb.northnews.cn/bfxb/html/2012–02/21/content_905525.htm.
[j] Website: http://paper.people.com.cn/zgnyb/html/2014–01/13/content_1377856.htm.
[k] Website: http://news.bjx.com.cn/html/20151222/694060.shtml.
[l] Website: http://www.xjalt.gov.cn/info/1033/282642.htm.
[m] Website: http://www.brj.gov.cn/Item/9093.aspx.

electricity theirself at all. At current status with serious wind energy rejection, the wind energy companies are forced to decease their electricity price (even up to zero) in order to obtain the quotations. The wind energy companies tolerate this low electricity price because comparing with rejection (zero profit), they could reduce the lost through the subsidies provided by the central government.

As a result, the thermal power plants benefit a lot from such kind of quotation system as they could earn profits without the generations of the electricity just through exchanging the quotation with the wind energy companies. At the same time, the quotation system do great harm to the wind energy companies, leading to serious economic losses. Due to its negative effects, most of the quotation exchange polices have been halted by the central government.

Appendix C. An overview of the wind energy heat-supply projects

In the winter, wind energy rejection becomes more serious in some parts of China (e.g. northeast and northwest China) because more thermal power plants should be operated to provide the heat to the local people (as well as generations of electricity). In order to solve this dilemma, the authorities are encouraging the wind energy heat-supply projects. In total, over 20 projects of this kind have been approved, under construction or commissioned (as listed in Table 21). The detailed information of such kind of projects are listed in Table 22 through a project in Inner Mongolia Autonomous Region.

Principally, comparing with other heat-supply methods (e.g. oil, coal and gas), the economic efficiency for the electricity heat-supply units is quite low (as shown in Table 23). However, due to serious wind energy rejection, the price of the electricity of heat-supply projects could be lowered through the following aspects:

1. Heat-supply company buys the electricity from the grid as normal. Generally, off-peak electricity (between 20:00 and 8:00) will be employed for the heat-supply units to control the cost.
2. Wind energy company will pay extra money to the heat-supply company (as generally shown in the agreement) because if the heat-supply company do not buy their electricity, those electricity will be rejected by the grid.

In current situations, the wind energy companies, heat supplying companies and grid companies could all benefit from the above process.

Appendix D. An overview of the hydrogen generation projects using wind energy

There are many kinds of hydrogen generation methods including electrolysis of water, coal-based method, natural gas pyrolysis and methanol-based method. Among those methods, the hydrogen generation through electrolysis of water is of great cost and is not economical. In order to relieve the wind energy rejection, several hydrogen generation projects based on wind energy have been funded by the central government as listed in Table 24. Among them, the Guyuan project in Hebei province is the largest hydrogen generation project of its kind in the world.

There are several limitations of the hydrogen generation through electrolysis of water using wind energy. Firstly, the project can be only constructed in the wind farm or nearby. Hence, the wind energy rejected by the grid can be directly employed for the hydrogen generation. Secondly, the market for hydrogen consumption in the local region is usually limited, leading to the selling problems. Thirdly, there exists great challenge for the storage and transportation of the generated hydrogen from the viewpoints of both safety and economic efficiency.

Appendix E. A case study of the specific reasons for the wind energy rejection in West Inner Mongolia

In this section, a brief case study on the paramount reasons for wind energy rejection in western Inner Mongolia will be provided. We select the West Inner Mongolia for in-depth discussions because the West Inner Mongolia is of great importance in China (also in world) in terms of installed capacity of wind energy and wind generated electricity (as shown in Table 25).

The paramount reasons for the wind energy rejection in the West Inner Mongolia are given as follows:

1. No enough transmission lines for the electricity transfer to the (electricity) demand center. The West Inner Mongolia grid company is unique because it is the only grid company governed by the local province. According the Electric Power Law, the West Inner Mongolia grid company could not invest the transmission lines across different grids (referring to Appendix A). Hence, the constructions of the transmission lines (also the operations) are totally under control of the State Grid. This leads

Table 22
A detailed description of the wind power heat-supply projects in Siziwang Banner in Inner Mongolia. The data were collected from Wang [97].

Items	Parameters
Commission time	Dec. 2014
Capacity of wind power plant (MW)	200
Number of wind turbines	100
Capacity of electric boiler (MW)	51.84
Number of Electric boilers	24
Capacity of thermal storage tank (m^3)	115
Number of thermal storage tanks	30
Heating supplying area (m^2)	500,000
Electricity consumed (GWh)	70[a]
Electricity price (RMB/kWh)	0.51[b]; 0.43[c]; 0.32[d]
Static investment of wind farm project (Million RMB)	132,462
System access cost (Million RMB)	2,300
Heating supplying system construction fee (Million RMB)	8,902
Loan interest during construction (Million RMB)	4,497.8
Dynamic investment (Million RMB)	148,161.8
Total investment financial rate of return (post-tax)	10.01%
Capital financial internal rate of return	12.53%
Payback period (post-tax)	8 years

[a] This parameter was calculated based on one heating period from October to May of the next year. Peak-time refers to the 21:00 to 8:00 of the next day (11 h in total).
[b] This is the benchmark electricity price of wind power in the grid according to the government's policy.
[c] This is the price paid by the heating companies for the electricity of wind energy from the grid company.
[d] This is the subsidies provided by the wind power company to the heating companies in order to avoid rejection.

Table 23
Comparisons between investment and cost of different kinds of heat-supply methods. This table was translated based on Hu [98]. This calculation was based on the heat-supply system in a certain city with heat-supply area one million square meters within 120 days, 18°, and 0.42 GJ/m^2.

Methods	Investment (RMB/m^2)	Cost (RMB/m^2)
Electricity	30.50	67.76
Oil	24.40	59.83
Gas	26.15	29.43
Coal	39.00	18.80

Table 24
Hydrogen generation projects using wind energy.

Name	Start time	Comments
Preliminary study on the technology of combining wind power with photovoltaic power by electrolysis of seawater for hydrogen production	2009	–
Research and demonstration of combined direct wind power hydrogen generation and fuel cell power generation system	Apr.2014	Hydrogen production power: 100 kW; Fuel cell generation power: 30 kW
Key technology of hydrogen storage with applications in renewable energy	Oct.2014	Hydrogen storage experimental platform: photovoltaic simulation: 30 kW; Hydrogen production from alkaline electrolytic water: 2 Nm^3/h; Hydrogen storage alloys: 16 Nm^3; Proton exchange membrane fuel cell: 10 kW
Hydrogen generation in Guyuan, Hebei province.	Apr.2015	Hydrogen production system by water electrolysis: 10 MW; Wind power plant: 200 MW; Hydrogen production capacity:17.52 million m^3
Hydrogen generation of Goldwind Science & Technology Company	–	Wind power plant: 100 MW; Hydrogen storage capacity: 10 MW

Table 25
The installed capacity and generated electricity of wind energy of 2015 in 8 leagues of the western Inner Mongolia (up to the end of 2015). The data were collected from the "Report of wind power generation Specialized Committee (1st , 2016)" released by the Inner Mongolia electric power association.

League	Installed Capacity (MW)	Electricity[a] (GWh)
Xilingol	3281.80	6270.48
Ulanqab	4900.65	8709.46
Hohhot	594.00	1222.54
Baotou	2968.92	3217.64
Ordos	247.30	540.47
Wuhai	–	–
Bayan Nur	2828.75	4701.61
Alxa	371.70	667.30
Total	15193.12	25329.50
Ratio[b] (%)	20.30%	8.65%

[a] This is the generated electricity in 2015.
[b] This is the ratio between the total installed capacity of wind energy or generated electricity by wind power to the same parameter of western Inner Mongolia.

to serious delays of the progress of the transmission lines.

2. Lack of the flexible units. Due to the long period for the heat supply during the winter in the western Inner Mongolia (up to a half of year), over a half of the thermal power plants could not be operated in variable loads. Other flexible units (e.g. oil-fired or gas-fired power plants) are also limited. For energy storage, there is only one pumped hydro energy storage power plant (located in Hohhot with total capacity 1,200 MW), which is not enough for the rapid wind energy development.

Appendix F. Policy issues for the wind energy rejection in Gansu province

In this appendix, we will discuss the influences of policies on the wind energy rejection. One of the example of those policies is the "Regulations on the administration of renewable energy power generation" released by the National Development and Reform Commission on Jan 2006 (referring to Table 13 for details). In this policy, the wind energy project with capacity below 50 MW could be approved by the local government while originally, all those projects should be approved by the central government. This policy indeed plays a positive role on the wind energy development in China but is also with some negative effects. Before the release of this policy, for the approval of the wind farm projects, the matched power demand and the constructions of transmission lines will be also evaluated. After the release of this policy, for the approval of the wind farm projects, such kind of evaluation of the matched resources (e.g. power demand and transmission lines) is not necessary or optional during the administration process of the local governments. As shown in the Appendix A, the transmission lines can only be built by two grid companies, which is beyond the control of local governments. Hence, serious energy rejection will occur eventually.

The influences of those policies will be further demonstrated using Jiuquan wind energy base in Gansu province, China. In the first phase of Jiuquan project, the planned installed capacity up to the end of 2010 is 3800 MW. However, the final installed capacity up to the end of 2010 is 5560 MW. The extra 1760 MW did not match the national plan made by the central government and the matched energy demand for wind energy and transmission lines are not available. Most of those extra wind farms (e.g. 35 projects with the size 49.5 MW) were approved by the Gansu local government in order to avoid the involvement of the central government. Through this process, the objectivities of the Gansu local government (e.g. increasing the local tax and attracting the wind turbine manufactures) were accomplished. However, without enough power demand in the Gansu province and transmission lines for inter-province electricity transfer, the wind energy rejection in the recent years is not a surprise.

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